TWO-PHASE PRESSURE LOSSES IN VALVES

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Master of Science in Chemical Engineering

By

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NOMENCLATURE

A	cross-sectional flow area, ft.^{2}
D	pipe diameter, ft.
f	friction factor as defined by Nikuradse equation, dimensionless
f_G	superficial friction factor for gas phase calculated from Reynolds number, Re_G, dimensionless
f_L	superficial friction factor for liquid phase calculated from Reynolds number, Re_L, dimensionless
g_c	conversion factor, 32.2 ft. lb. mass/sec.^{2} lb. force
L	length, ft.
P_{AVG}	average pressure in test section, psia.
P	pressure, lb. force/in.^{2}, or in. Hg
Q_G	flow rate, CFM, at standard conditions
Q_L	flow rate, GPM
Re_G	superficial Reynolds number of gas phase based on inside pipe diameter, dimensionless
Re_L	superficial Reynolds number of liquid phase based on inside pipe diameter, dimensionless
T_G	temperature of gas phase, °C
T_L	temperature of liquid phase, °C
u_G	superficial velocity of air based on inside pipe diameter, ft./sec.
u_L	superficial velocity of water based on inside pipe diameter, ft./sec.
W_G	gas flow rate, lb. mass/sec.

NOMENCLATURE (Continued)

X^2	the ratio of the pressure drop for the flow of liquid alone to the pressure drop for the flow of the gas alone, dimensionless
μ_G	viscosity of gas phase, lb. mass/ft. sec.
μ_L	viscosity of liquid phase, lb. mass/ft. sec.
ρ_L	liquid density, lb. mass/ft.^{3}
ϕ^2_{LTT}	parameter used by Lockhart and Martinelli (2), the ratio of the two-phase pressure drop per unit length to the pressure drop per unit length of the liquid phase (subscript L) flowing alone in the pipe, dimensionless. The subscript TT denotes that both the liquid and gas phases are turbulent as defined in reference (2)
ψ	single-phase equivalent length multiplying factor, dimensionless
ΔP_{EXP}	experimental pressure drop, in. Hg, or psi., as designated
$\left(\frac{\Delta P}{\Delta L}\right)_{TP}$	two-phase pressure drop per unit length calculated by correlation of Lockhart and Martinelli (2), psi./ft.
L/D	ratio of length to diameter of pipe or method used to express length equivalent of valve or fitting in regard to causing pressure loss, dimensionless
$(L/D)_{TS}$	ratio of length to diameter of pipe for test section, dimensionless
$(L/D)_V$	ratio determined for valve studied, dimensionless
$\frac{\epsilon}{D}$	relative roughness, dimensionless

SUMMARY

With increasing application made of two-phase gas-liquid flow, a study of this type of flow in various standard valves was considered necessary. The following study on 1 inch pipe is a continuation of the work on 1 1/2 inch pipe presented by Robert McKinlock Sharp as a thesis at the Georgia Institute of Technology (1).

In developing the two-phase flow, air was used as the gas phase and water as the liquid phase. An apparatus was used that would allow metered amounts of both phases to be passed through various standard valves. Air rates varied from about 0.003 to 0.040 pounds per second (2.50 to 15.57 SCFM) with varying water rates of 2 to 30 gallons per minute. Seven different air rates were used at each water rate.

The data obtained were compared with the previous data compiled by Sharp (1). Agreement was found to be within the accuracy predicted by the correlation of Lockhart and Martinelli (2). Using this correlation, it was found that pressure losses in systems containing valves could be predicted by applying a multiplying factor to the single-phase equivalent lengths of the valves. This multiplying factor is presented as a function of X^2, the ratio of the pressure drop for the flow of the liquid alone to the pressure drop for the flow of the gas alone.

CHAPTER I

INTRODUCTION

The purpose of this study was to obtain information concerning two-phase pressure losses in valves, this investigation being a continuation of the original work done on this topic by Sharp (1) in 1956.

The recent development of interest in two-phase flow problems has been caused, mainly, by the many new industrial applications in which two-phase flow occurs. Due to these industrial applications much progress has recently been made in this field. As a more complete understanding of these phenomena evolves, an increase will be made in the usefulness of older operations involving two-phase flow. Some of the more widely known of these operations involve evaporation, boiling, flashing, condensation, and evolution of dissolved gases.

An examination of the literature has indicated that, in practically all investigations to date, air or natural gas has been used as the gas phase; and water, benzene, and hydrocarbon oils have been used as the liquid phase. Most of the information available (2, 3, 4, 5, 6, 7, 8, 9) is for co-current flow of the two phases in straight horizontal and vertical cylindrical ducts, ranging in size from capillary tubes to two inch pipes. Work has been done on systems with and without mass transfer between phases. Summaries of this work are given in references (11) and (12).

A noticeable characteristic found in gas-liquid flow systems is the existence of various flow patterns. The change from one flow pattern to the next usually occurs with no definite transition point. These flow patterns depend on the relative amounts and velocities of the phases; the nature of the phases, i.e., viscosity, density, etc.; the geometry of the piping; entrance effects; and external vibrations and pulsations.

When starting with a horizontal pipe running full of liquid and adding increasing amounts of a gaseous phase, the following seven flow patterns have been observed in two-phase flow:

1) bubble flow, in which bubbles of the gas move along the top of the pipe at approximately the same velocity as the liquid;

2) stratified flow, in which the gas occupies the upper portion and the liquid the lower portion of the pipe with a smooth interface between the phases;

3) wave flow, in which the interface is disturbed by waves;

4) plug flow, in which large plugs of vapor and liquid move along the pipe with the liquid phase controlling;

5) slug flow, in which rapidly moving slugs of liquid move along the pipe with the gas phase controlling;

6) annular flow, in which a high velocity gas stream flowing in a central core causes the liquid phase to assume an annular flow channel against the pipe wall; and

7) mist flow, in which the liquid drops are distributed throughout the continuous gas phase.

For clarification and future reference the flow patterns observed during the experimental program are plotted as a function of the air and water rates. This plot is shown in Fig. 1.

In the previous work by Sharp (1) an effort was made to use the correlation of Lockhart and Martinelli (2) with the standard single-phase

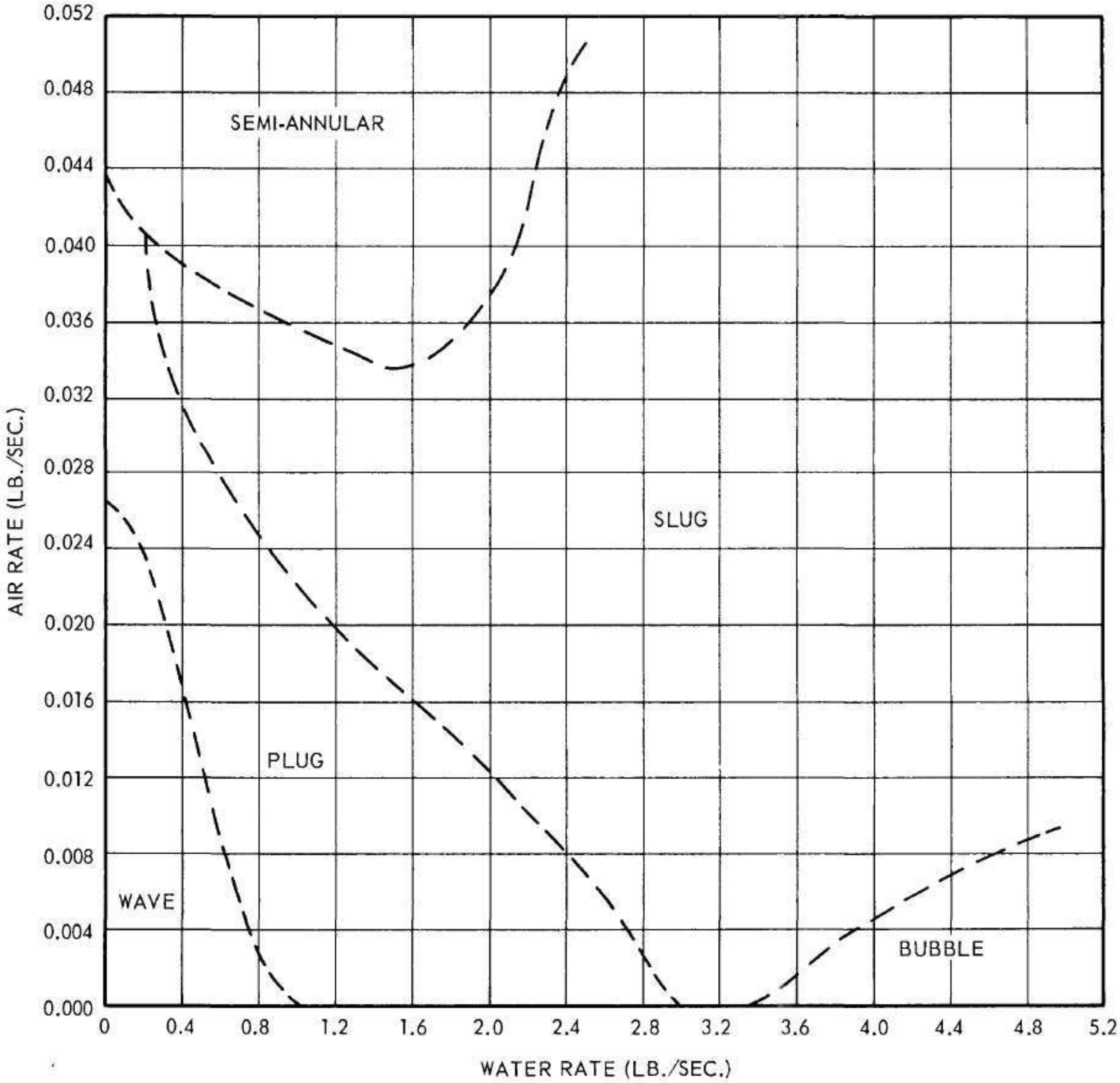

Figure 1. Observed Flow Patterns for Co-Current Flow of Air-Water Mixture in 1 Inch Schedule 40 Horizontal Pipe.

equivalent length for the valves studied to predict pressure losses. All the pressure drops calculated by this method gave values higher than those determined experimentally. As a result a multiplying factor was applied to the single-phase equivalent length for use with the Lockhart and Martinelli correlation (2). Such a multiplying factor was determined and found to depend upon the ratio of the mass flow rates of the water and air phases. This corrected equivalent length allowed the prediction of pressure drops that were within ± 25 per cent of the majority of the experimental values examined. The following equation was used to calculate the single-phase equivalent length multiplying factor, designated ψ, for the valves.

$$\left(\frac{\Delta P}{\Delta L}\right)_{TP}\left[\left(\frac{L}{D}\right)_{TS} D_{TS} + \psi\left(\frac{L}{D}\right)_{V} D_{TS}\right] 2.035 = \Delta P_{EXP} \qquad (1)$$

The experimental data for the correlation proposed by Sharp (1) was taken from a test section 338 inches long with 1 1/2 inch Pyrex Double Tough glass pipe. The following study was made to check this correlation, using 1 inch schedule 40 steel pipe.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

Schematic flow diagrams of the experimental apparatus are shown in Figs. 2 and 3. Photographs of portions of the equipment are shown in Figs. 4 through 7.

The apparatus used in this experiment was basically the same as that used by Sharp (1) in his work. The only major changes made were in the actual test section where 1 inch schedule 40 pipe was substituted for the 1 1/2 inch glass pipe used previously.

The following components made up the apparatus used in this experiment: instrumentation for measuring the mass flow rate, the temperature, and the pressure of the air and water phases separately; a pipe section for mixing the phases; the test section consisting of the valve under investigation and a total pipe length of 194 inches; pressure measuring instruments for determining the pressure drop across the test section and the absolute pressure in the test section; and a separator for removing the air from the water phase so that the water could be recycled.

The Air Supply System.--The air for this experiment was supplied by an Ingersoll-Rand 50 CFM compressor. The compressed air was brought into an 8 cubic foot storage tank at a pressure between 90 and 125 psig. Upon entering and leaving the storage tank, the air was passed through glass wool filters to eliminate foreign matter. The air from the storage tank was regulated by two different size needle valves which served as coarse and fine adjustments. From these valves the air passed through a 3/8-inch

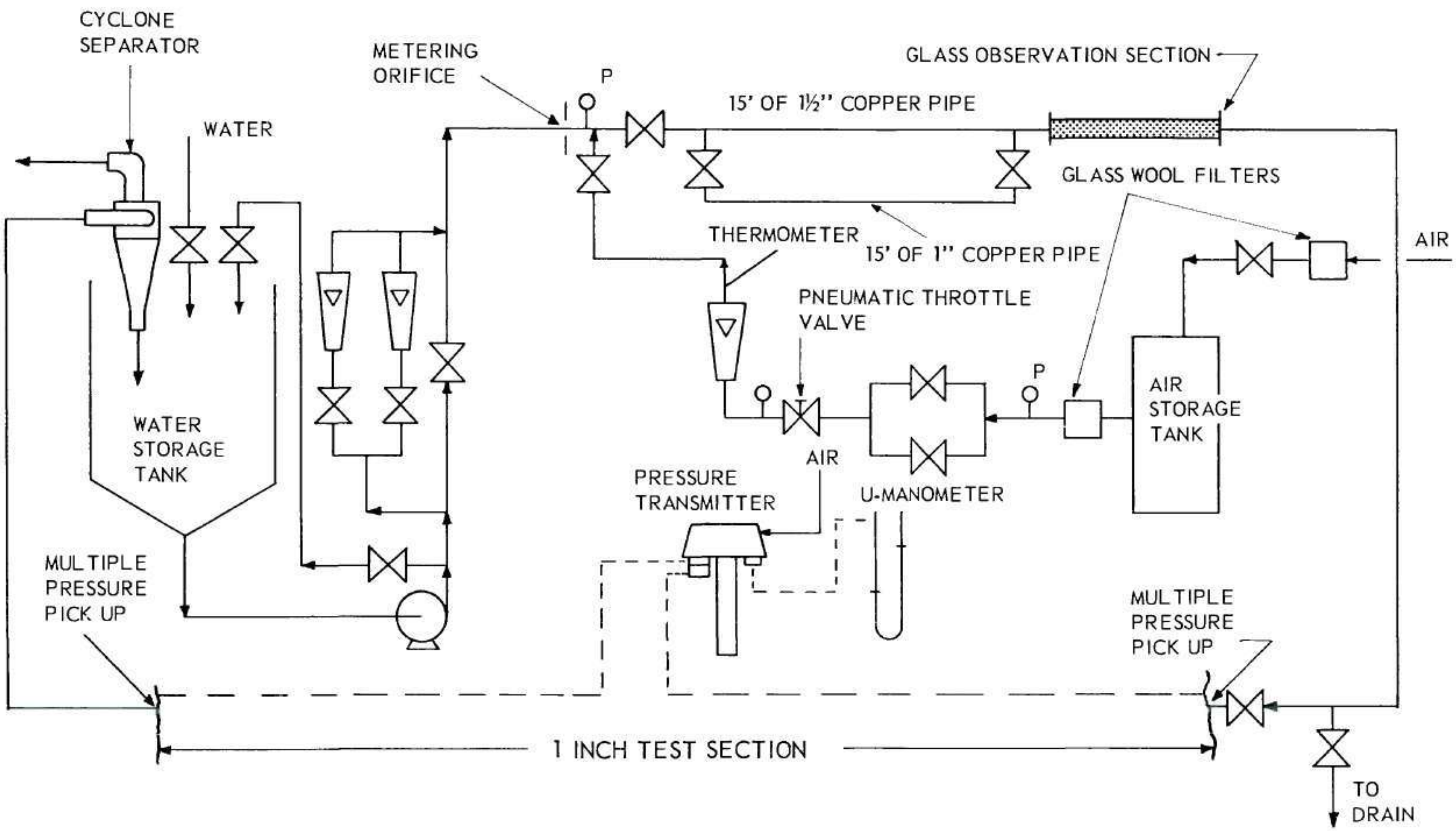

Figure 2. Schematic Diagram of Experimental Apparatus.

NOTE: ALL PIPE IN 194 INCH TEST SECTION IS
1 INCH SCHEDULE 40 IRON PIPE VISUAL
OBSERVATION SECTIONS ARE 1 INCH
PYREX DOUBLE TOUGH GLASS PIPE

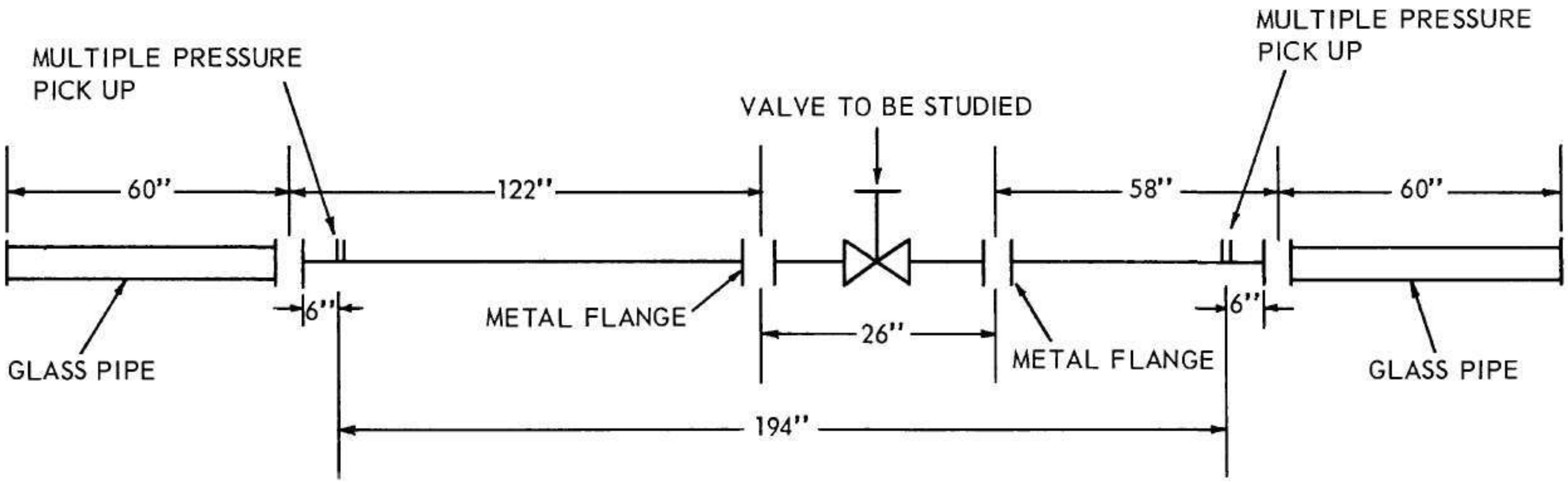

Figure 3. Piping Diagram of Experimental Test Section.

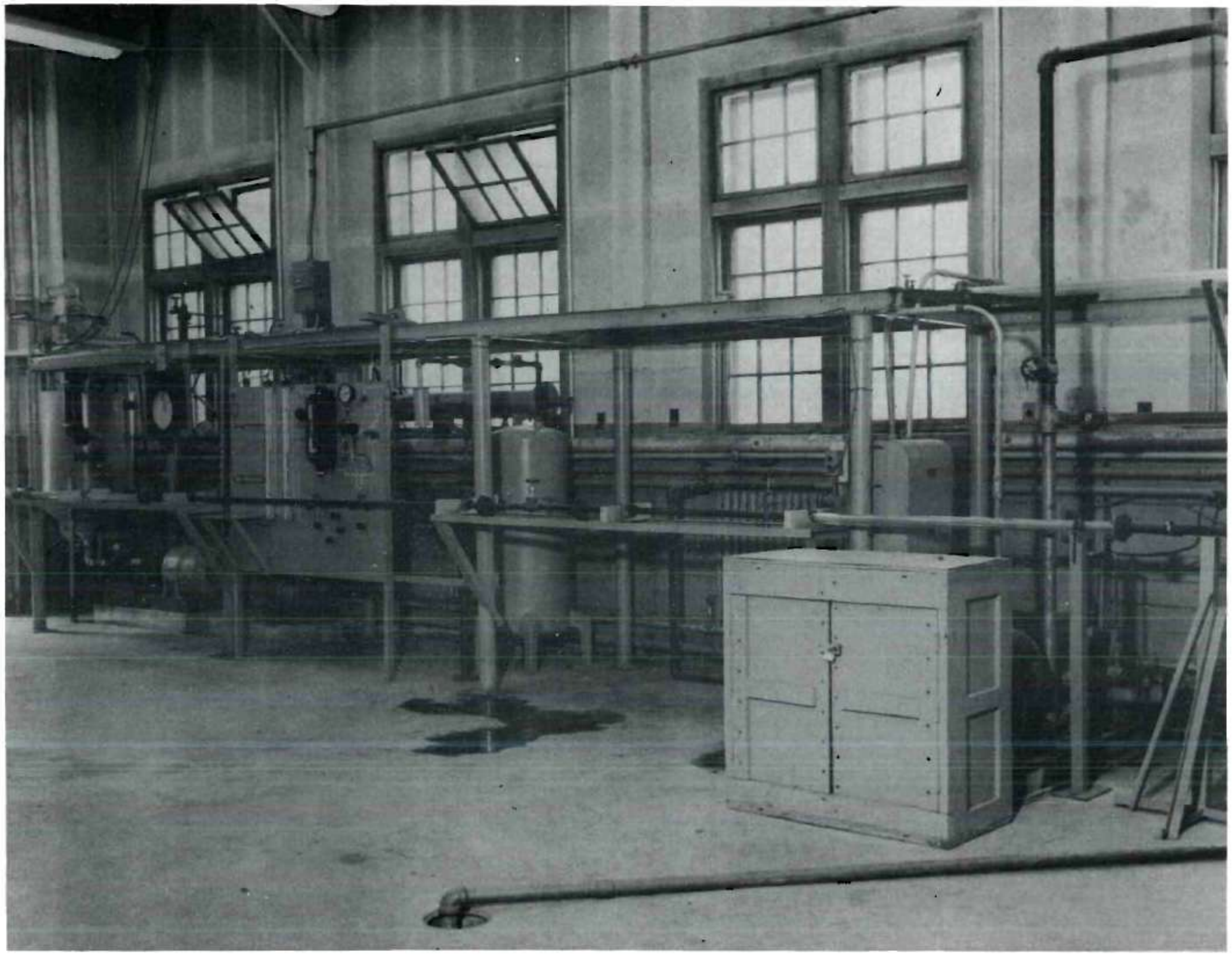

Figure 4. Experimental Apparatus.

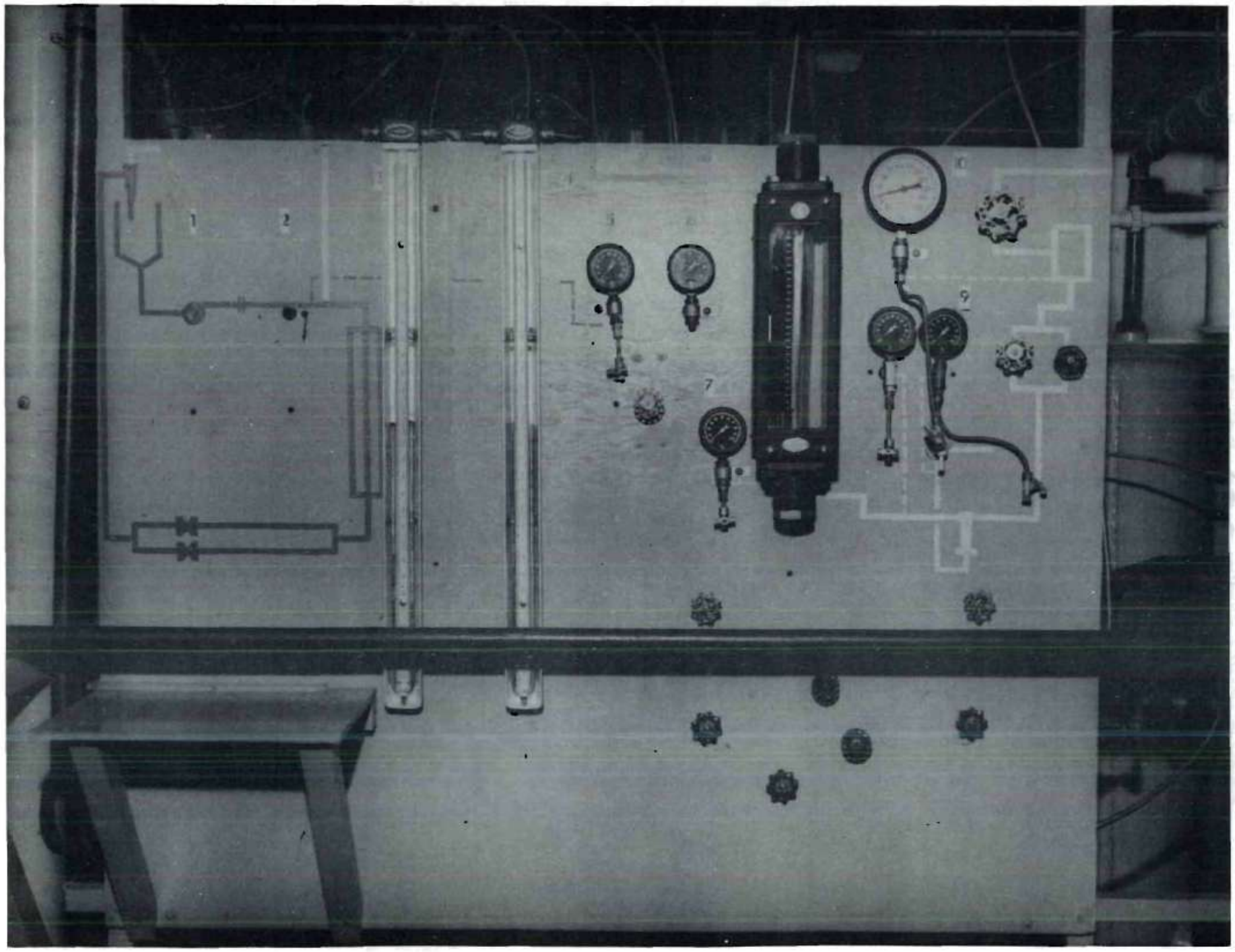

Figure 5. Control Panel.

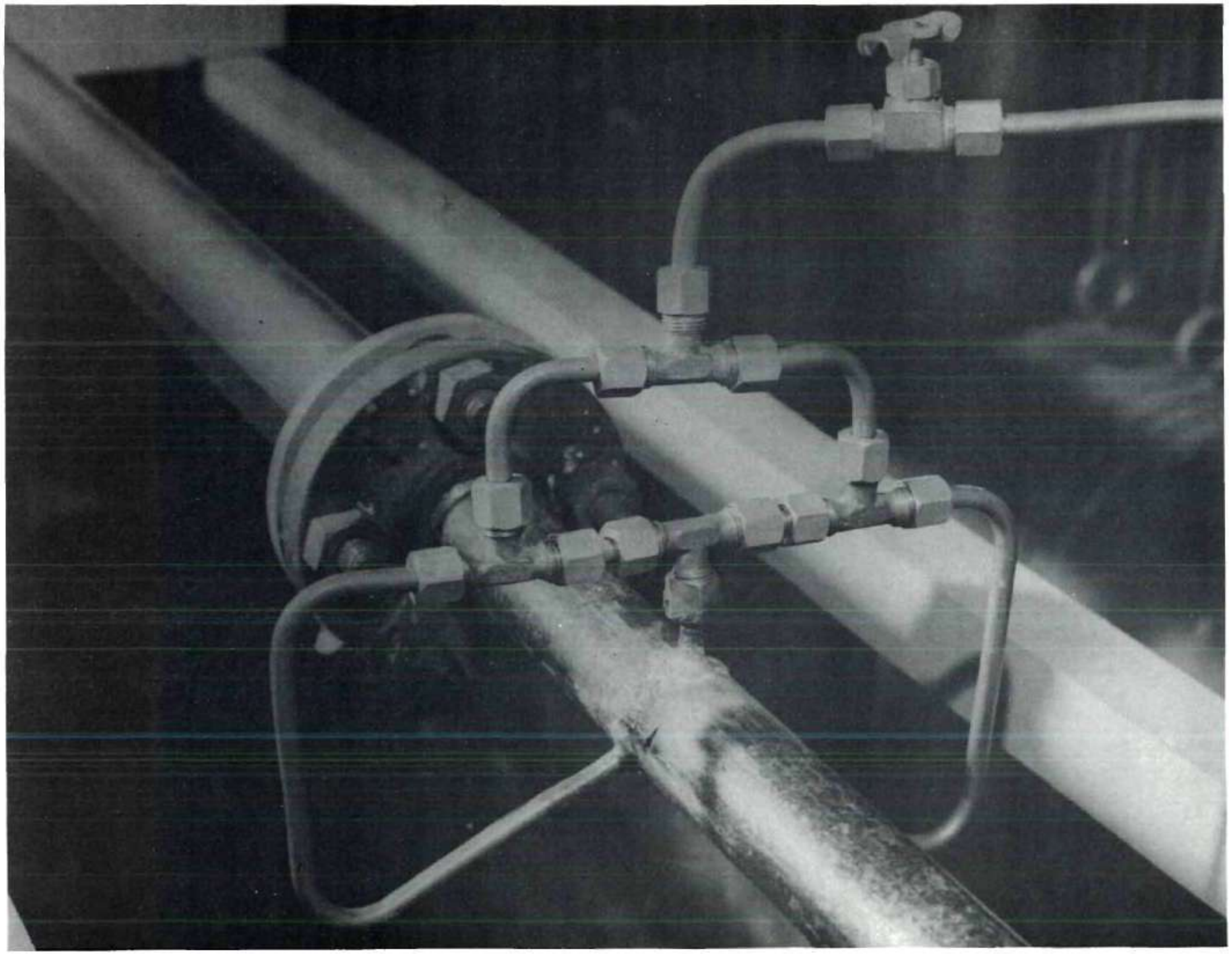

Figure 6. Pressure Pick-Up Device.

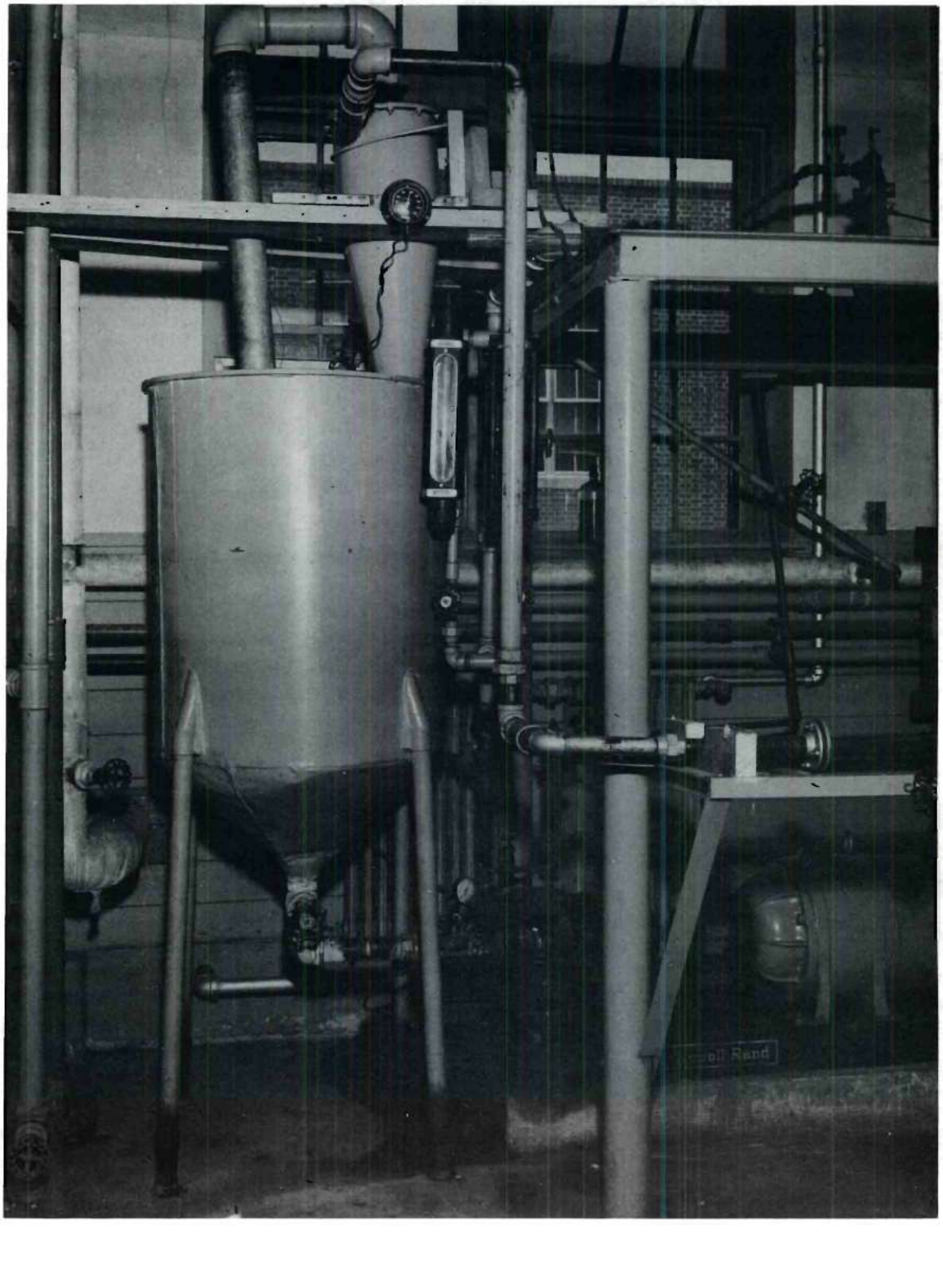

Figure 7. Water Storage Tank with Pump and Cyclone Separator.

Klipfel diaphragm type throttle valve operated pneumatically. This throttling valve allowed the line pressure to be reduced from the tank pressure to any desired value. From the throttle valve the air passed into a Schutte and Koerting Model 18200 Safeguard Rotameter fitted with a number 6-F-10 aluminum rotor. The calibration curve for this instrument was furnished by the manufacturer. The rotameter assembly was provided with a pressure gage calibrated in this laboratory and a thermometer. Leaving the rotameter the air passed directly into the mixing system. The air entered the mixing section from a piece of 3/8-inch pipe which was teed at 90 degrees into the 1 1/2 inch water supply line. The end of the 3/8-inch pipe, after being brazed into the water pipe, was carefully rounded so that it would conform to the interior surface of the water line. Figure 5 shows the air supply control panel.

The Water Supply System.--The water supply system was composed of a conical bottom storage tank which held about 125 gallons, and an Ingersoll-Rand 1 CORVNL pump having a capacity of 75 GPM against a head of 120 feet. The flow rates were metered by one of two methods. At low flow rates, 2 to 14 GPM, two small rotameters mounted in parallel were used. A bypass line equipped with a metering orifice calibrated in this laboratory was used for flow rates above 14 GPM. The water storage tank was equipped with a thermometer.

The Mixing Section.--The mixing section consisted of 15 feet of 1 1/2 inch copper pipe flanged to a 5 foot section of Pyrex Double Tough 1 1/2 inch glass pipe, a long sweep 90 degree drainage elbow, a 1 1/2 inch to 1 inch standard reducer, and several additional feet of 1 inch schedule 40 pipe which served to connect the mixing section with the test section. The mixing section was composed of 1 1/2 inch piping, rather than 1 inch, to reduce the total pressure drop of the system and increase the output capacity of the pump. The 15 foot straight length of copper pipe was fitted at each end with pressure taps which were connected by 3/8-inch copper tubing to the pressure drop measuring components. This copper pipe was used in the preliminary calibration of the apparatus.

The Test Section.--The test section used in the pressure drop determinations consisted of 194 inches of 1 inch schedule 40 pipe. Flanged to each end of the test section was a 5 foot section of 1 inch Pyrex Double Tough glass pipe. The purpose of this glass pipe was to permit visual study of the flow patterns during the test section runs. The test section contained two sets of standard 1 inch flanges from 10 to 12 inches on either side of the test valve. The flanges were fitted tightly with rubber gaskets of slightly less than 1 inch diameters. The flanges and gaskets were well centered.

In the measurement of pressure losses for single-phase flow in valves an accepted practice is to locate the upstream pressure pick-up at least 15 pipe diameters above the valve and the downstream pick-up about 50 diameters below the valve. However, there is no standard criterion for the location of pick-ups in a valve system where two-phase flow is encountered.

A preliminary study of this phenomenon was deemed advisable. Upstream of a test valve was placed a 5 foot section of 1 inch schedule 40 pipe with ten pick-ups located every five pipe diameters upstream of the valve. Nine pick-ups were placed downstream of the valve 15 pipe diameters apart. By passing a constant water rate through the test section and recording the pressure losses between various combinations of pick-ups, it was found that the disturbance of the flow caused by the test valve had ceased 15 pipe diameters upstream and 50 pipe diameters downstream of the valve. This was in accordance with the accepted values for single-phase flow. To determine the location of the pressure pick-ups for two-phase flow the same procedure was followed at various air and water rates. From the data obtained no definite conclusions were drawn other than the fact that at 60 pipe diameters upstream of the valve and 120 diameters downstream no disturbance of the flow was encountered. For a complete understanding of flow disturbance caused by valves and pressure pick-up locations for two-phase flow, a separate study of this problem would be necessary.

In the actual test section the pick-ups were located 62 pipe diameters upstream of the test valve and 123 diameters downstream.

<u>The Pressure Measuring Instruments</u>.--Fig. 6 illustrates one of the two multiple pressure tap devices used in the test section. The pressure impulses from these tap devices were transmitted through water-filled 3/16-inch copper tubing to a Republic pneumatic differential pressure transmitter. This device was calibrated in position before being used against known water pressures. The output air signal from the transmitter was read on a 30 inch U-tube mercury filled manometer. A Bourdon type pressure gage calibrated in this laboratory was connected to the upstream pressure pick-up to allow calculation of an average pressure in the test section.

<u>The Separation Device</u>.--A small cyclone separator shown in Fig. 7 was used for separation of the air and water phases upon passage through the test section. The water leaving the cyclone dropped into the storage tank to be recycled.

CHAPTER III

EXPERIMENTAL PROCEDURE

The first phase of the experimental program was the checking of the accuracy of the instruments. The accuracy of the pressure drop measuring system was checked by making a series of single phase-water runs in the 15 foot 1 1/2 inch copper pipe. These experimental values of pressure drops were compared with those calculated by usual methods. Following this, a second series of runs was made in the copper pipe with co-current flow of air and water mixtures. These runs were made to check the accuracy of the air system instruments and to compare the pressure drop results with those of other investigators in this field. Next, similar runs were made in the test section with the test valve removed and a straight section of schedule 40 pipe in its place. A complete range of water and air rates were run to simulate an actual test run on a valve. These values were compared with those values predicted by the Lockhart and Martinelli (2) correlation.

The second phase of the experimental program was the test runs made on the various standard valves. Seven different air rates varying from approximately 0.003 to 0.040 pounds per second (2.50 to 15.57 SCFM) were run with various water rates from 2 to 30 GPM. The same air and water rates were run for every valve as far as possible, and each valve was tested in the full open and half closed positions. A more exact identification of the valves studied in this series of tests is presented in Appendix I.

The operating procedure was essentially the same for all the runs, both in the test section and in the copper pipe. For a typical test run on a test valve, first, the water rate was set at the initial rate of 2 GPM. The pressure tap lines were opened and filled with water. After all the air had been forced from the pressure tap lines, measurements were recorded at a water rate of 2 GPM. These measurements included the water temperature, the water rate, the pressure drop across the test section, and the absolute pressure in the test section. A complete set of measurements was made from 2 to 30 GPM. The water rate was then returned to a value slightly above 2 GPM for the beginning of the two-phase runs. The air rate was set at the initial value of 2.50 SCFM, and the air was bled to the atmosphere. At this flow rate the air was forced into the mixing pipe at a pressure slightly above the pressure in the mixing section. The water rate was set at 2 GPM and measurements were recorded. These measurements included the following; water rate, water temperature, air rate, air temperature, air pressure, pressure drop across the test section, and the absolute pressure in the test section. A series of measurements was made over a complete air range from 2.50 to 15.57 SCFM at a constant water rate of 2 GPM. The air rate was returned to 2.50 SCFM and the water rate was increased to the next value. This procedure was repeated until a complete range of water rates had been covered. The system was then shut down and a new test valve was placed in the line. The complete experimental data is shown in Table 3.

CHAPTER IV

DISCUSSION OF RESULTS

The data and calculated results are presented in Tables 1 and 2 and Figs. 8 through 13. The original data are on file in the School of Chemical Engineering of the Georgia Institute of Technology.

Copper Pipe Section.--In an effort to calibrate the equipment and to determine the accuracy of the pressure drop measuring components, a series of preliminary runs was made in a 15 foot section of copper pipe whose inside diameter was 1.60 inches. This was the same pipe section used in the previous work done by Sharp (1). Pressure drop measurements made at various water rates agreed within 5 per cent of values calculated by using the standard friction factor-Reynolds number plot. As a final check on the air system and the pressure drop measuring components, a complete series of air and water runs was made in the 1.60 inch I. D. copper section. The data obtained in these runs were compared with the values predicted by the correlation of Lockhart and Martinelli (2). The experimental values are within ± 20 per cent of the predicted values. All data obtained during the experimental runs agree very well with the previous data of Sharp (1) on the 1.60 I. D. copper pipe section.

Test Section.--The test section consisted of 194 inches of 1 inch schedule 40 pipe with a measured average inside diameter of 1.049 inches. To determine the relative roughness of the test pipe, pressure drops were measured for a series of water rates through the test section with a straight piece of pipe replacing the test valve. The relative roughness was calculated from the friction factor-Reynolds number plot using the experimental pressure drop, and a value of 0.003 was determined. This value is somewhat larger than a relative roughness of 0.002 predicted for 1 inch schedule 40 pipe. After a complete check of the test section including the pressure taps, possible leaks in the pressure tap lines, and upstream and downstream effect of the flanges on the pressure taps, it was concluded that the experimentally determined value of 0.003 for the relative roughness was correct for this particular pipe.

After all equipment checks and preliminary calculations had been made, two-phase pressure drops were measured in the test section with no valve in place. The data obtained from these runs together with the appropriate calculations may be found in Table 1. A comparison of these values with those predicted by the Lockhart and Martinelli (2) correlation is shown in Fig. 10. These values fall within the accuracy of the correlation with most values falling approximately 25 per cent above the correlating curve.

Fig. 9 shows a plot of air rate versus pressure drop with the parameter of constant water rate, constructed from the straight test section data with no valve in the line. This plot became the standard for computing the no-length pressure drop curves shown for several of the valves in Figs. 10 through 12. The no-length pressure drop is the pressure drop in the test section caused by the test valve. The no-length values were obtained by subtracting from the total pressure drop of the test section with a test valve the corresponding pressure drop of the test section without a test valve. This allowed the construction of a no-length pressure drop plot for any of the test valves.

These no-length pressure drop plots follow the same trend as those presented by Sharp (1) for 1 1/2 inch Pyrex Double Tough glass pipe. At low water rates the no-length pressure drop increases nearly linearly with increasing air rates. At higher water rates small amounts of air cause much greater pressure drops, but at increasing air rates the pressure drop increase becomes less. Thus, the conclusion is drawn that the greatest relative increase in pressure loss occurs at high liquid rates and low air rates. Due to the capacity of the pump and the large pressures encountered, 20 GPM was usually the maximum water flow that could be obtained with a valve in the line.

A large portion of the discrepancy in the experimental data can be attributed to the difficulty encountered in reading the pressure drops. As in any two-phase flow system, constantly changing flow patterns cause a continuous fluctuation of the manometers. At low pressure drops the fluctuations gave values which varied as much as 100 per cent. In the region of wave flow, low water and air rates, the fluctuations had considerable amplitude but a relative low frequency. As the air rates were increased and plug flow developed, the amplitude of the fluctuations decreased, and the frequency increased. At higher water rates and low air rates both the amplitude and the frequency were quite high. Increasing air rates caused the amplitude to lessen and the frequency to increase. The flow pattern was changed from plug to slug flow, and in this region the slugging shook the apparatus violently.

Prior to each experimental run on a test valve, pressure drops were measured for the complete range of water rates. From these values the single-phase L/D for the valve was determined by standard friction factor-Reynolds number calculations. The calculated L/D usually agreed within ± 10 per cent with values found in the literature for standard valves, full open. But the L/D for the valves 1/2 closed (meaning in this report one-half total turns closed) often varied as much as ± 40 per cent with the values found in the literature. In all cases, the calculated L/D was used as the single-phase L/D in the calculations of the equivalent length factor ψ in the following equation:

$$\left(\frac{\Delta P}{\Delta L}\right)_{TP}\left[\left(\frac{L}{D}\right)_{TS} D_{TS} + \psi\left(\frac{L}{D}\right)_{V} D_{TS}\right] 2.035 = \Delta P_{EXP} \qquad (1)$$

It follows from this equation that if the L/D for the test section is large in comparison with the L/D for the valve studied, very accurate experimental pressure drop measurements are needed to calculate ψ, since the result is strongly influenced by the L/D for the test section. Because the single-phase L/D for the gate valve is so small and the pressure drop measurements were difficult to read at low pressure drops, no calculation was made for the multiplying factor, ψ, for this valve. The method of calculation is shown in Appendix III and the results of the calculations are summarized in Table 2.

These values for ψ were plotted as a function of the mass ratio of air and water for each valve. In comparison with the correlation curve presented by Sharp (1), the calculated values usually fell within 40 per cent of the predicted values. As might be suspected from the comparison of experimental data with the Lockhart and Martinelli (2) correlation in Fig. 8, the calculated values of ψ were in general larger than those predicted by Sharp (1). At both very high water to air rates and very low water to air rates, the ψ factor approached one.

In the work done by Sharp (1) few experimental values of ψ were calculated at these low water to air rates; therefore, the correlation curve is not completed in this region. A slight increase in the amount of air in this region causes a relatively large increase in the multiplying factor; thus, the accuracy of the prediction of the pressure drop is rather questionable. From a study of these data plotted as ψ versus the ratio of mass flow rates, it was concluded that the multiplying factor ψ did not depend only on the ratio of the flow rates. In an effort to find a more complete correlation for ψ several standard parameters for two-phase flow were investigated. The conclusion was that X^2 was the parameter that contained most of the variables affecting ψ. By plotting the multiplying factor as a function of X^2 a much smoother correlation curve was obtained. This correlation is shown in Fig. 13. The maximum deviation of the experimental data is 40 to 45 per cent and the average deviation is approximately 25 per cent. Values calculated by Sharp (1) for the 1 1/2 inch test section fall within minus 40 per cent of the correlation curve.

To calculate the pressure drop for any standard valve, it is necessary to know only the single-phase L/D, X^2, and $(\Delta P/\Delta L)_{TP}$. These values and the correlation presented in Fig. 13 permit the no-length pressure drop to be calculated within an accuracy of $\pm$ 40 per cent.

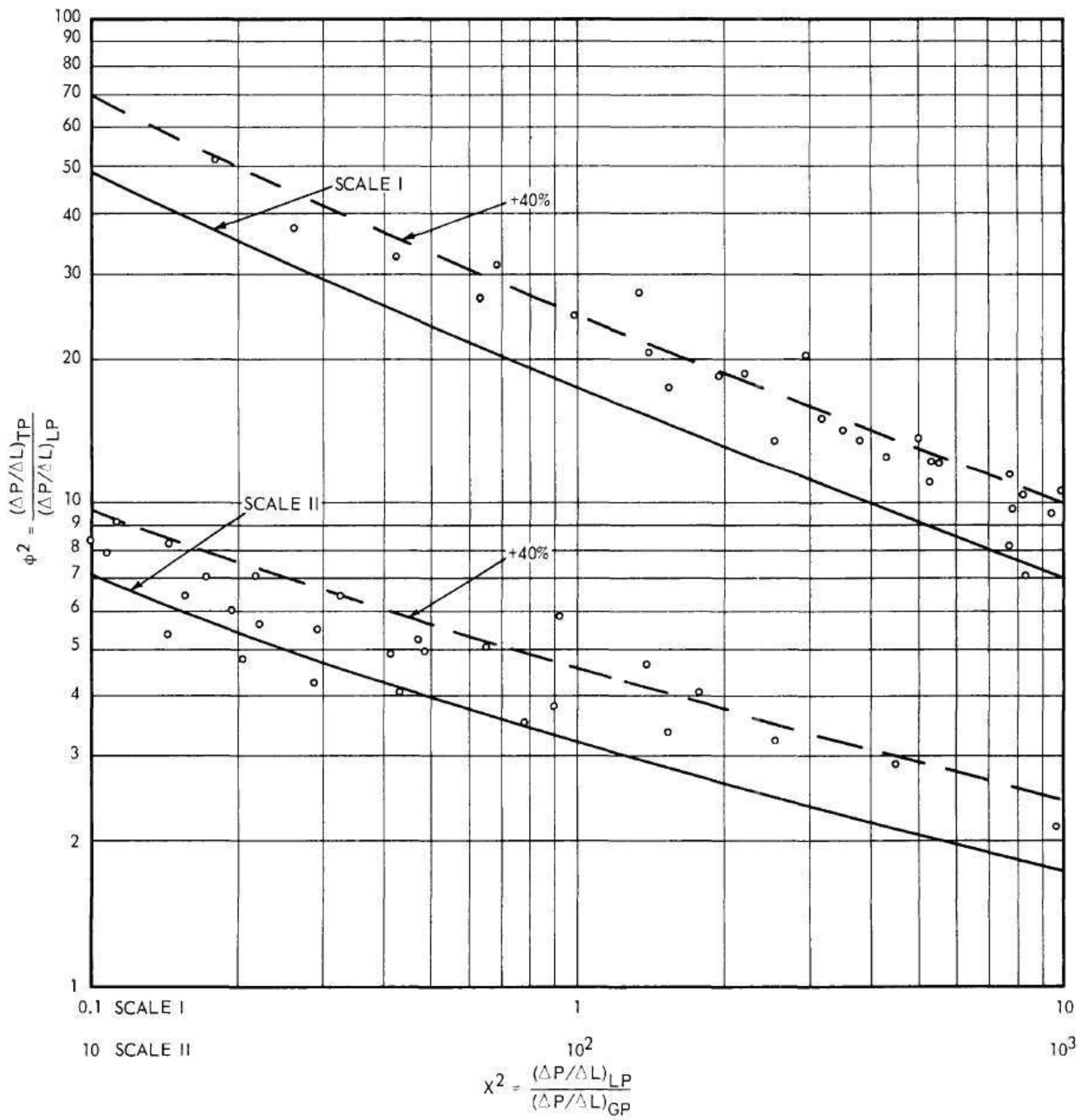

Figure 8. Comparison of Calibration Data on 194 Inch Straight Horizontal Section of 1 Inch Schedule 40 Pipe for Co-Current Turbulent-Turbulent Flow of Air and Water with Correlation of Lockhart and Martinelli.

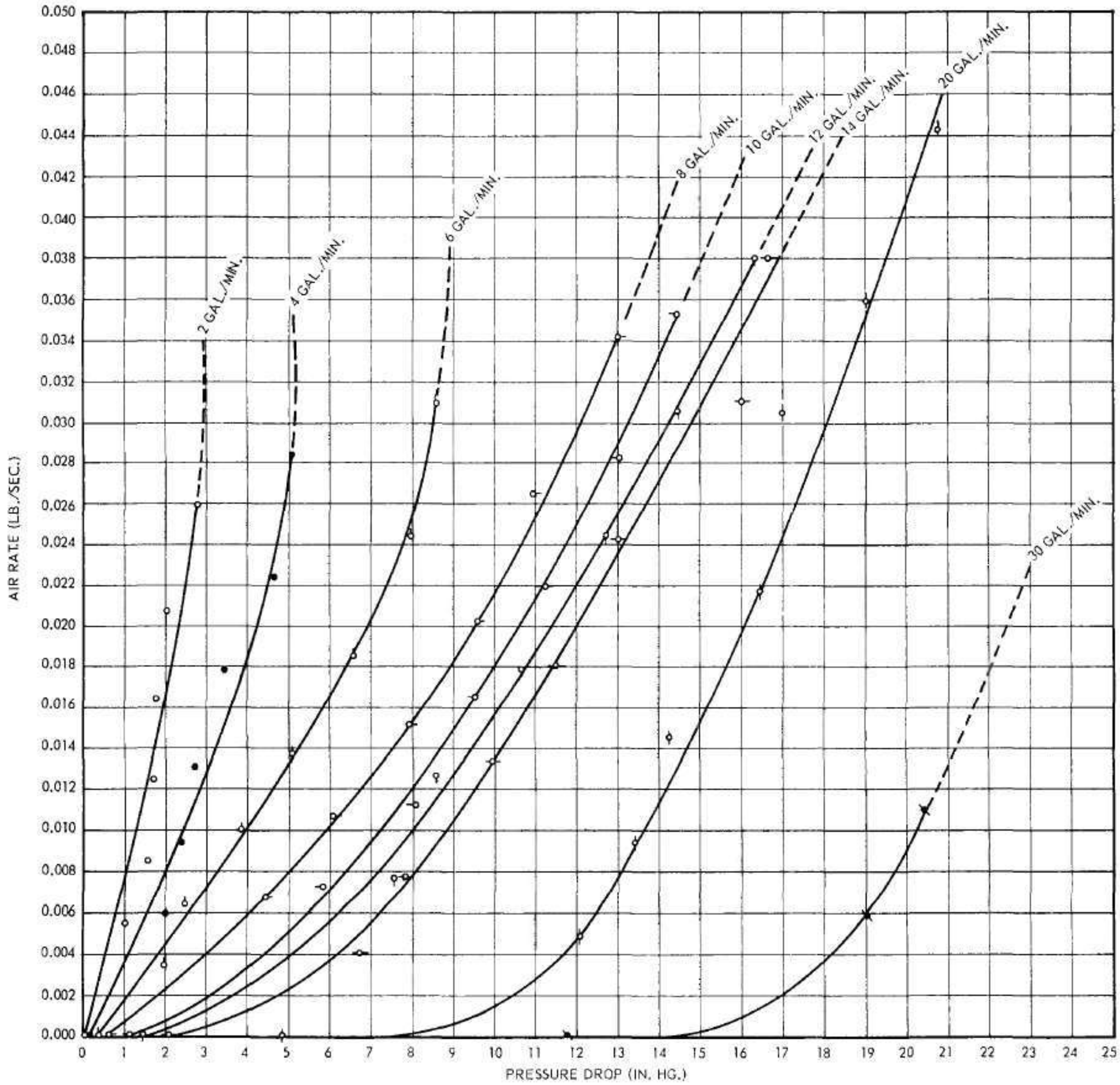

Figure 9. Air Rate versus Pressure Drop at Constant Water Rates for 194 Inch Straight Horizontal 1 Inch Test Section with No Valves.

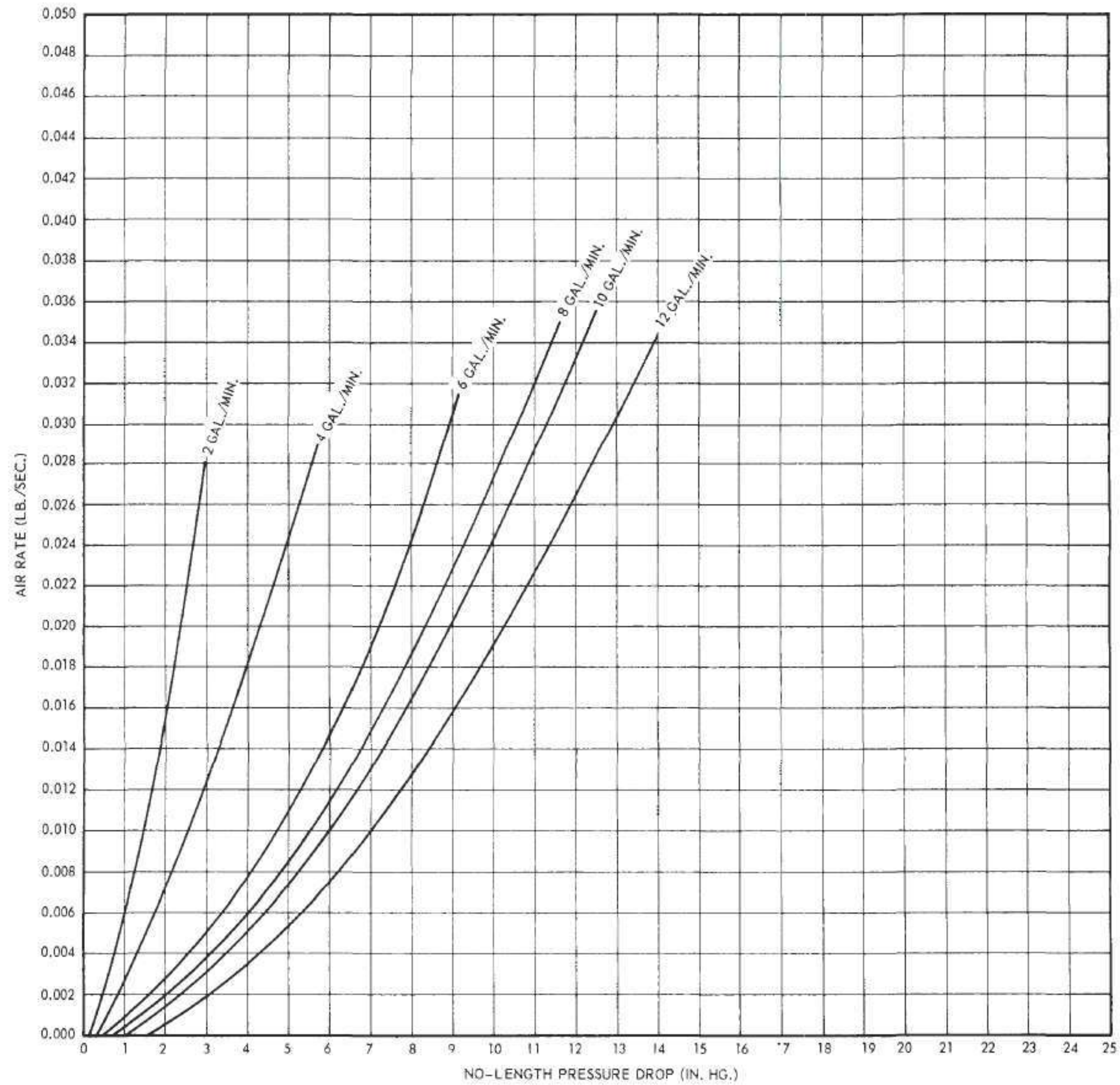

Figure 10. No-Length Pressure Drop versus Air Rate at Constant Water Rates--1 Inch Plug Disc Globe Valve, Full Open.

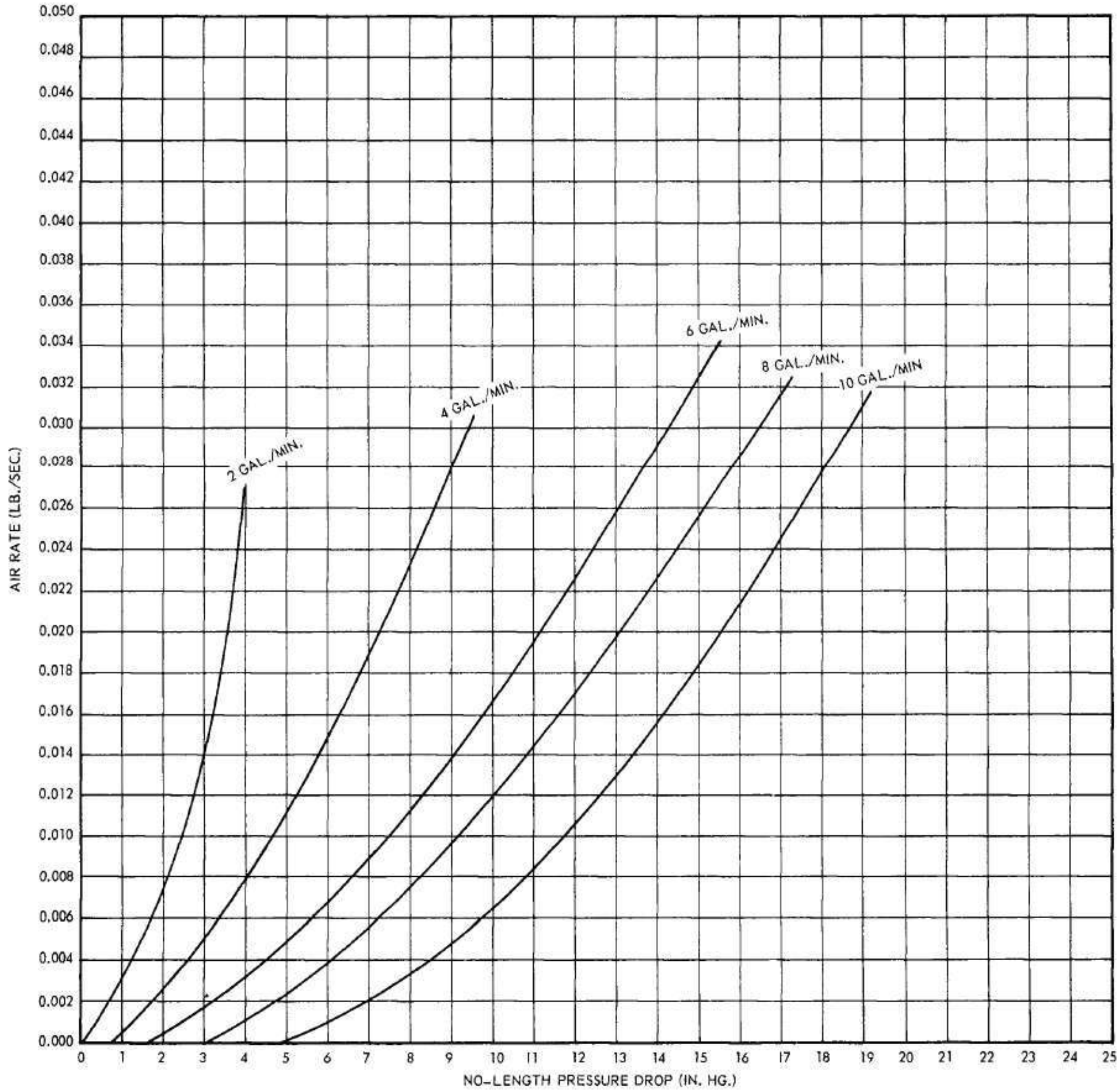

Figure 11. No-Length Pressure Drop versus Air Rate at Constant Water Rates--1 Inch Plug Disc Globe Valve, 1/2 Closed.

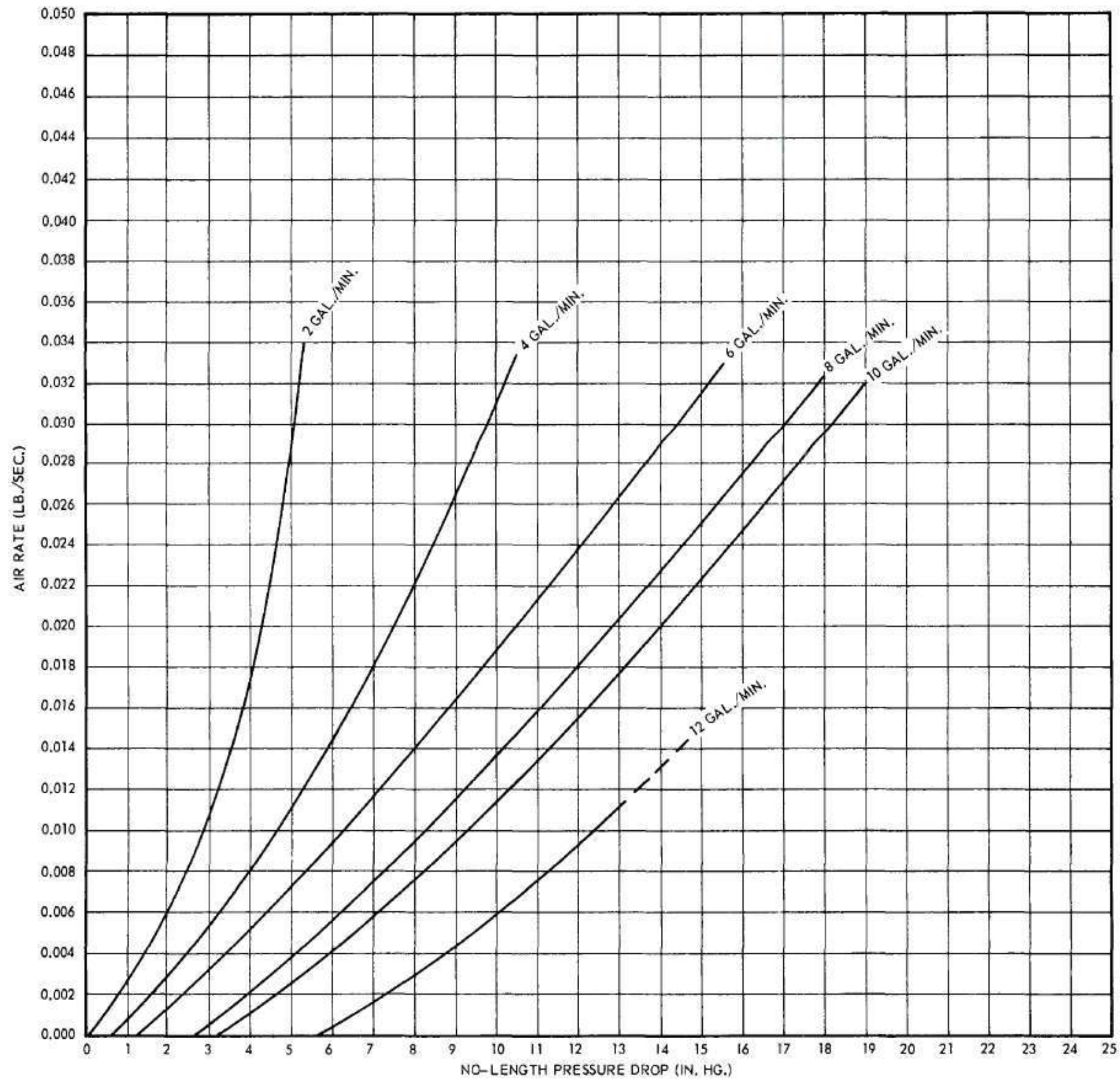

Figure 12. No-Length Pressure Drop versus Air Rate at Constant Water Rates--1 Inch Gas Line Cock Valve, 1/2 Closed.

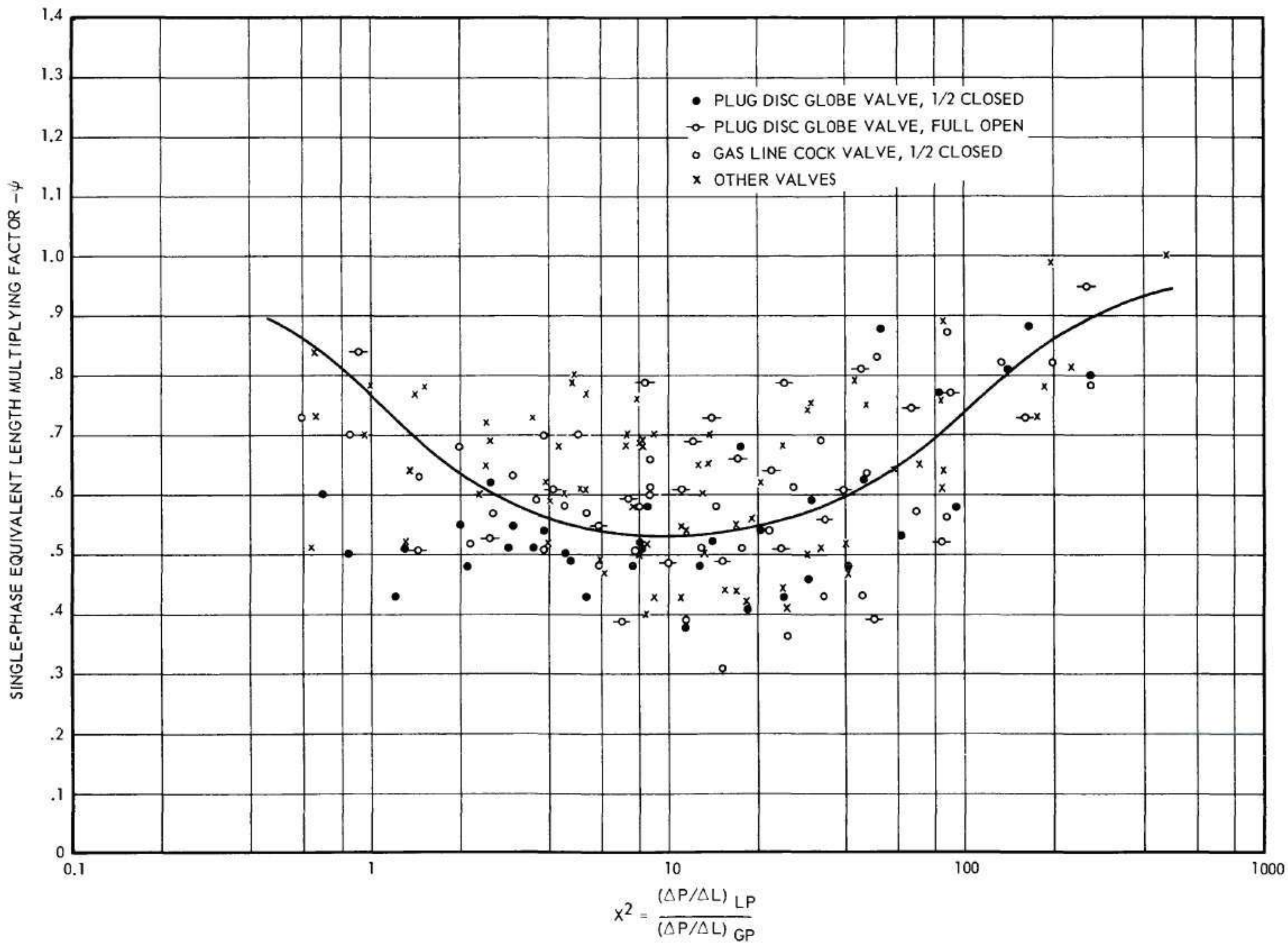

Figure 13. Correlation Curve Showing Single-Phase Equivalent Length Multiplying Factor versus X^2.

Table 1. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long without Valve

Run No.	Q_L GPM	W_G lb./sec.	$P_{AVG.}$ psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G
10	2	0.0031	14.9	16.57	2.00	8.30	7.50	12.44	88.48
11	2	0.0056	14.9	16.57	5.61	2.95	11.28	18.70	49.41
12	2	0.0086	14.9	16.41	12.14	1.35	15.56	25.53	32.25
13	2	0.0125	14.9	16.41	24.10	0.68	20.74	34.03	22.22
14	2	0.0166	15.7	16.41	38.69	0.42	25.35	41.60	16.76
15	2	0.0208	15.1	16.41	62.15	0.26	31.06	50.96	13.30
16	2	0.0260	16.0	16.41	88.94	0.18	36.24	59.47	10.68
17	4	0.0032	14.6	57.73	2.11	27.36	4.83	27.88	173.43
18	4	0.0060	16.0	57.61	5.88	9.80	7.04	40.57	92.48
19	4	0.0094	16.0	57.62	13.32	4.32	9.69	55.81	58.94
20	4	0.0131	17.3	57.62	22.69	2.54	12.00	69.15	42.34
21	4	0.0178	18.5	57.62	37.61	1.53	14.77	85.10	31.16
22	4	0.0225	18.5	57.62	58.80	0.98	17.79	102.50	24.59
23	4	0.0285	18.6	57.62	91.46	0.63	21.43	123.47	19.44
24	6	0.0036	15.1	122.24	2.53	48.22	3.98	48.61	229.84
25	6	0.0065	17.5	122.24	6.29	19.44	5.46	66.70	127.15
26	6	0.0101	18.7	122.24	13.00	9.40	7.15	87.44	82.28
27	6	0.0138	19.3	122.24	22.42	5.45	8.84	108.00	60.26
28	6	0.0186	19.7	122.24	38.61	3.17	10.98	134.16	44.58
29	6	0.0245	20.3	122.24	62.72	1.95	13.37	163.47	33.95
30	6	0.0310	23.0	122.24	87.09	1.40	15.32	187.20	26.77
31	8	0.0037	17.1	210.19	2.31	91.11	3.24	68.00	301.21
32	8	0.0068	18.4	210.19	6.46	32.53	4.54	95.55	162.42
33	8	0.0107	18.5	210.19	14.70	14.30	6.11	128.38	103.22
34	8	0.0152	18.9	210.19	27.27	7.71	7.72	162.26	73.14
35	8	0.0202	21.3	210.19	41.75	5.03	9.12	191.67	54.70
36	8	0.0266	24.8	210.19	60.26	3.49	10.56	221.87	41.60
37	8	0.0342	25.3	210.19	95.01	2.21	12.70	266.86	32.45
38	10	0.0038	18.2	320.90	2.30	139.78	2.86	91.65	364.33

Table 1. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long without Valve

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G
39	10	0.0073	20.0	320.90	6.75	47.53	4.00	128.24	189.19
40	10	0.0112	19.6	320.90	15.09	21.26	5.28	169.52	123.24
41	10	0.0165	21.2	320.90	28.57	11.23	6.68	214.53	83.84
42	10	0.0220	26.7	320.90	39.06	8.22	7.53	241.70	62.83
43	10	0.0283	28.1	320.90	59.72	5.37	8.89	285.20	48.92
44	10	0.0354	30.5	320.90	84.54	3.80	10.20	327.42	39.10
45	12	0.0041	18.7	455.33	2.54	179.03	2.66	121.25	406.34
46	12	0.0077	21.3	455.33	6.98	65.21	3.60	164.09	215.25
47	12	0.0127	23.7	455.33	15.67	29.06	4.73	215.28	130.78
48	12	0.0179	26.5	455.33	26.54	17.15	5.71	260.04	92.89
49	12	0.0245	28.0	455.33	45.41	10.03	6.98	317.79	67.91
50	12	0.0306	33.6	455.33	58.11	7.84	7.67	349.28	54.24
51	12	0.0382	34.9	455.33	85.29	5.34	8.91	405.70	43.54
52	14	0.0041	20.5	611.17	2.36	258.98	2.41	147.38	469.29
53	14	0.0078	22.3	611.17	6.87	88.92	3.27	199.78	246.89
54	14	0.0127	25.0	611.17	14.86	41.14	4.19	256.36	152.50
55	14	0.0181	26.4	611.17	27.26	22.42	5.18	316.76	107.01
56	14	0.0243	31.9	611.17	39.46	15.49	5.93	362.40	79.61
57	14	0.0311	35.3	611.17	56.86	10.75	6.80	415.44	62.34
58	14	0.0382	37.7	611.17	78.96	7.74	7.71	471.04	50.78
59	20	0.0049	24.3	1220.88	2.69	454.46	2.10	256.33	556.45
60	20	0.0094	26.5	1220.88	7.98	152.91	2.78	339.82	295.62
61	20	0.0146	30.7	1220.88	15.59	78.32	3.40	415.13	190.11
62	20	0.0217	35.7	1220.88	28.28	43.17	4.13	503.85	127.77
63	20	0.0285	39.8	1220.88	42.71	28.58	4.76	580.56	97.14
64	20	0.0360	44.4	1220.88	59.93	20.37	5.36	654.96	76.89
65	20	0.0443	47.1	1220.88	84.23	14.50	6.08	741.88	62.51
66	30	0.0059	32.8	2699.32	2.80	964.48	1.79	482.44	702.30
67	30	0.0110	36.3	2699.32	7.88	342.38	2.25	606.51	376.18

Table 2A. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gate Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G
77	2	.0032	14.9	16.41	1.99	8.25	7.52	12.34	87.77
78	2	0.0059	14.7	16.41	6.12	2.68	11.74	19.26	46.97
79	2	0.0089	15.8	16.41	12.10	1.36	15.53	25.49	31.00
80	2	0.0123	16.3	16.41	21.04	0.78	19.58	32.13	22.57
81	2	0.0165	16.3	16.41	36.37	0.45	24.69	40.52	16.83
82	2	0.0214	16.2	16.41	60.11	0.27	30.61	50.24	12.93
83	2	0.0266	16.5	16.41	89.16	0.18	36.28	59.53	10.40
84	4	0.0032	16.3	57.50	1.82	31.65	4.59	26.39	175.31
85	4	0.0063	16.7	57.50	6.06	9.49	7.13	40.98	87.85
86	4	0.0095	17.1	57.50	12.42	4.63	9.43	54.21	58.44
87	4	0.0132	17.8	57.50	21.90	2.63	11.84	68.08	42.07
88	4	0.0172	18.8	57.50	34.16	1.68	14.20	81.68	32.20
89	4	0.0229	18.5	57.50	59.66	0.96	17.92	103.02	24.17
90	4	0.0281	18.3	57.30	88.65	0.65	21.19	121.47	19.74
91	6	0.0035	16.2	122.04	2.23	54.81	2.81	46.53	235.01
92	6	0.0063	17.6	122.04	5.75	21.22	5.29	64.51	131.76
93	6	0.0098	18.7	122.04	12.19	10.01	6.98	85.22	84.35
94	6	0.0140	20.2	122.04	21.76	5.61	8.74	106.65	59.14
95	6	0.0191	20.5	122.04	38.26	3.19	10.94	133.55	43.42
96	6	0.0247	20.6	122.04	61.67	1.98	13.29	162.19	33.66
97	6	0.0301	22.3	122.04	82.91	1.47	15.01	183.25	27.65
98	8	0.0037	16.5	210.12	2.38	88.31	3.27	68.83	298.69
99	8	0.0069	17.5	210.12	6.77	31.05	4.62	97.06	161.06
100	8	0.0108	19.1	210.12	14.19	14.80	6.03	126.68	102.36
101	8	0.0149	19.7	210.12	24.78	8.48	7.44	156.36	74.55
102	8	0.0201	19.6	210.12	43.96	4.78	9.30	195.58	55.09
103	8	0.0267	23.8	210.12	61.90	3.39	10.67	224.22	41.52
104	8	0.0335	25.5	210.12	89.21	2.36	12.38	260.03	33.09
105	10	0.0039	18.3	320.90	2.32	138.49	2.86	91.90	357.28

Table 2A. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gate Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G
106	10	0.0071	19.7	320.90	6.36	50.44	3.91	125.73	195.05
107	10	0.0109	20.2	320.90	13.66	23.50	5.10	163.54	126.70
108	10	0.0163	20.3	320.90	28.55	11.24	6.68	214.47	84.99
109	10	0.0215	23.8	320.90	41.04	7.82	7.68	246.36	64.42
110	10	0.0284	25.3	320.90	65.48	4.90	9.22	295.75	48.79
111	10	0.0350	27.9	320.90	88.69	3.62	10.40	333.78	39.57
112	12	0.0040	18.1	454.52	2.44	186.76	2.62	119.63	419.53
113	12	0.0076	19.2	454.45	7.36	61.74	3.67	116.70	219.02
114	12	0.0119	21.5	454.52	15.03	30.23	4.66	211.94	139.52
115	12	0.0168	22.9	454.52	26.73	17.00	5.73	260.42	99.03
116	12	0.0231	25.6	454.52	43.63	10.41	6.89	312.63	72.01
117	12	0.0295	26.5	454.52	67.35	6.75	8.13	369.44	56.30
118	12	0.0368	26.5	454.52	102.78	4.42	9.60	436.32	45.17
119	14	0.0041	18.8	610.88	2.52	242.65	2.45	149.83	469.87
120	14	0.0078	20.2	610.88	7.33	83.29	3.34	203.77	248.91
121	14	0.0126	22.2	610.88	16.26	37.58	4.33	264.24	153.33
122	14	0.0180	24.8	610.88	28.29	21.59	5.25	320.92	107.41
123	14	0.0242	26.1	610.88	46.68	13.09	6.31	385.60	80.23
124	14	0.0310	29.3	610.88	67.14	9.10	7.24	442.43	62.41
125	14	0.0385	34.5	610.88	86.15	7.09	7.97	487.06	50.35
126	20	0.0049	23.6	1220.88	2.69	454.47	2.10	256.33	56.95
127	20	0.0091	26.4	1220.88	7.48	163.18	2.73	333.63	30.38
128	20	0.0145	28.1	1220.88	16.65	73.32	3.47	423.86	19.05
129	20	0.0204	30.7	1220.88	28.90	42.25	4.16	507.53	13.55
130	20	0.0283	35.5	1220.88	46.38	26.32	4.90	597.65	9.78
131	20	0.0358	40.0	1220.88	64.61	18.90	5.51	673.03	7.73
132	20	0.0432	44.5	1220.88	83.47	14.63	6.06	739.41	64.08

Table 2A. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gate Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G
133	30	0.0058	30.5	2701.70	2.85	949.34	1.79	484.37	716.85
134	30	0.0109	34.2	2701.70	8.09	334.10	2.26	610.72	379.39
135	30	0.0161	39.0	2701.70	14.48	186.64	2.63	711.19	258.45

Table 2B. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gate Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G
147	2	0.0031	14.9	15.93	1.98	8.06	7.59	12.09	87.94
148	2	0.0056	14.7	15.93	5.51	2.89	11.38	18.13	49.75
149	2	0.0088	14.6	15.93	12.62	1.26	16.01	25.50	31.58
150	2	0.0125	14.6	15.93	24.30	0.66	21.07	33.57	22.13
151	2	0.0166	14.5	15.93	41.61	0.38	26.48	42.20	16.65
152	2	0.0208	15.0	15.93	61.19	0.26	31.24	49.80	13.32
153	2	0.0266	15.8	15.93	93.11	0.17	37.44	59.65	10.39
154	4	0.0032	15.3	56.54	1.94	29.20	4.72	26.69	175.26
155	4	0.0063	15.7	56.54	6.39	8.85	7.32	41.40	88.28
156	4	0.0094	16.1	56.54	12.96	4.36	9.65	54.57	59.02
157	4	0.0135	16.9	56.54	24.06	2.35	12.39	70.03	41.12
158	4	0.0174	17.2	56.54	38.10	1.48	14.96	84.62	31.85
159	4	0.0225	17.4	56.54	61.32	0.92	18.25	103.19	24.60
160	4	0.0283	18.2	56.54	90.54	0.62	21.51	121.62	19.58
161	6	0.0036	15.6	120.74	2.40	50.34	3.92	47.34	229.96
162	6	0.0068	16.9	120.74	6.81	17.72	5.64	68.14	122.54
163	6	0.0103	17.2	120.74	14.37	8.40	7.47	90.16	80.64
164	6	0.0143	17.6	120.74	25.92	4.66	9.40	113.54	57.92
165	6	0.0191	19.7	120.74	39.81	3.03	11.17	134.85	43.38
166	6	0.0241	20.5	120.74	59.27	2.04	13.13	158.56	34.43
167	6	0.0305	21.0	120.74	90.44	1.34	15.64	188.79	27.24
168	8	0.0037	16.1	208.14	2.40	86.85	3.29	68.53	301.31
169	8	0.0069	18.6	208.14	6.37	32.69	4.54	94.45	160.90
170	8	0.0106	19.1	208.14	13.69	15.20	5.97	124.27	104.27
171	8	0.0153	20.2	208.14	25.44	8.18	7.54	157.03	72.45
172	8	0.0203	21.4	208.14	40.86	5.09	9.08	188.91	54.61
173	8	0.0262	21.8	208.14	65.05	3.20	10.93	227.46	42.32
174	8	0.0337	23.8	208.14	96.63	2.15	12.84	267.16	32.87
175	10	0.0038	18.2	318.63	2.27	140.60	2.85	90.85	362.63

Table 2B. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gate Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G
176	10	0.0074	19.0	318.63	7.08	45.01	4.07	129.67	187.45
177	10	0.0115	20.1	318.63	15.14	21.04	5.30	168.94	120.04
178	10	0.0162	20.9	318.63	27.34	11.66	6.59	210.07	85.57
179	10	0.0218	21.7	318.63	46.19	6.90	8.06	256.79	63.49
180	10	0.0289	23.1	318.63	74.09	4.30	9.71	309.30	47.93
181	10	0.0361	25.4	318.63	103.31	3.08	11.09	353.42	38.35
182	12	0.0040	24.0	452.01	2.47	182.65	2.65	119.70	416.56
183	12	0.0077	28.7	452.01	7.07	63.90	3.63	163.09	216.93
184	12	0.0122	33.2	452.01	15.77	28.67	4.75	214.71	136.22
185	12	0.0171	36.7	452.01	27.21	16.61	5.78	261.18	96.91
186	12	0.0228	40.7	452.01	42.97	10.52	6.85	309.77	72.83
187	12	0.0297	47.2	452.01	64.85	6.97	8.03	362.83	55.96
188	12	0.0366	52.2	452.01	89.07	5.07	9.09	410.87	45.35
189	14	0.0042	26.2	608.88	2.48	245.35	2.45	148.92	465.14
190	14	0.0079	30.2	608.88	7.30	83.38	3.33	203.03	246.72
191	14	0.0127	36.2	608.88	15.89	38.31	4.30	261.66	152.20
192	14	0.0186	43.2	608.88	29.0	210.03	5.31	323.01	104.21
193	14	0.0244	46.7	608.88	44.41	13.71	6.20	377.74	79.33
194	14	0.0312	52.2	608.88	65.31	9.32	7.18	436.90	62.08
195	14	0.0388	58.7	608.88	86.58	7.03	8.00	487.04	49.90
196	20	0.0046	22.6	1218.29	2.56	476.13	2.08	253.05	599.38
197	20	0.0091	28.6	1218.29	6.83	178.41	2.67	324.73	305.49
198	20	0.0148	30.8	1218.29	15.79	77.15	3.42	416.23	186.50
199	20	0.0212	35.7	1218.29	26.65	45.72	4.05	493.20	130.52
200	20	0.0278	40.3	1218.29	39.61	30.75	4.64	564.70	99.40
201	20	0.0354	45.0	1218.29	56.22	21.67	5.25	639.18	78.17
202	20	0.0444	47.4	1218.29	82.54	14.76	6.04	735.33	62.36
203	30	0.0059	31.1	2696.35	2.89	933.07	1.80	485.06	702.78
204	30	0.0112	35.7	2696.35	8.11	332.42	2.26	610.28	369.88
205	30	0.0180	38.5	2696.35	18.21	148.14	2.81	757.48	230.14

Table 2C. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Plug Disc Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
215	2	0.0033	16.5	16.62	1.98	8.41	7.47	12.41	83.62	0.61
216	2	0.0059	16.3	16.62	5.53	3.01	11.21	18.63	47.20	0.98
217	2	0.0089	16.2	16.57	11.82	1.40	15.32	25.39	31.15	1.01
218	2	0.0120	16.0	16.57	20.83	0.80	19.42	32.19	23.04	1.01
219	2	0.0168	15.9	16.57	38.81	0.43	25.28	41.90	16.56	0.80
220	2	0.0222	15.7	16.57	66.85	0.25	31.91	52.88	12.49	0.78
221	2	0.0275	16.4	16.57	95.95	0.17	37.29	61.80	10.10	0.93
222	4	0.0036	15.7	58.37	2.39	24.42	5.03	29.34	154.41	0.79
223	4	0.0065	16.0	58.37	6.72	8.68	7.37	43.04	85.58	0.60
224	4	0.0098	16.3	58.15	14.01	4.15	9.85	57.25	56.57	0.61
225	4	0.0131	16.6	58.15	23.52	2.47	12.13	70.55	42.31	0.53
226	4	0.0184	17.2	58.15	42.67	1.36	15.50	90.15	30.19	0.51
227	4	0.0230	17.7	58.15	63.49	0.92	18.30	106.43	24.09	0.84
228	4	0.0299	21.7	58.15	85.29	0.68	20.73	120.52	18.54	1.12
229	6	0.0037	15.9	123.15	2.48	49.74	3.94	48.48	225.30	1.43
230	6	0.0066	16.2	123.15	6.90	17.86	5.63	69.30	125.61	0.98
231	6	0.0104	16.9	123.15	14.94	8.42	7.52	92.63	80.43	0.89
232	6	0.0147	17.5	123.15	27.53	4.47	9.56	117.69	56.68	0.91
233	6	0.0191	18.8	123.15	41.79	2.95	11.30	139.13	43.67	0.99
234	6	0.0249	21.4	123.15	61.17	2.01	13.20	162.51	33.35	0.93
235	6	0.0316	23.0	123.15	89.21	1.38	15.42	189.90	26.35	0.89
236	8	0.0038	16.1	211.57	2.54	83.40	3.33	70.54	293.86	1.11
237	8	0.0070	16.8	211.57	7.34	28.84	4.74	100.29	158.46	0.85
238	8	0.0113	19.4	211.57	15.22	13.90	6.17	130.58	98.28	0.73
239	8	0.0159	21.8	211.57	25.49	8.30	7.50	158.73	69.94	0.79
240	8	0.0213	23.1	211.46	41.78	5.06	9.10	192.41	52.16	0.81
241	8	0.0274	24.3	211.57	64.46	3.28	10.82	228.85	40.42	0.84

Table 2C. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Plug Disc Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
242	8	0.0347	27.7	211.57	88.50	2.39	12.30	260.24	31.99	0.84
243	10	0.0040	17.5	323.05	2.57	125.70	2.95	95.16	347.78	1.12
244	10	0.0076	20.2	323.05	7.12	45.36	4.06	131.13	181.86	0.81
245	10	0.0119	21.9	323.05	14.78	21.85	5.23	168.97	116.87	0.64
246	10	0.0112	24.1	323.05	26.79	12.06	6.51	210.26	80.69	0.69
247	10	0.0233	25.7	323.05	44.49	7.26	7.90	255.22	59.61	0.59
248	10	0.0297	28.6	323.05	63.73	5.07	9.09	293.84	46.68	0.70
249	10	0.0363	32.0	323.05	83.62	3.86	10.13	327.30	38.20	0.70
250	12	0.0042	20.0	457.06	2.45	186.30	26.34	120.38	397.18	1.09
251	12	0.0079	22.8	457.06	6.81	67.13	3.57	163.19	209.24	0.75
252	12	0.0122	24.5	457.06	13.98	32.69	4.54	207.42	135.97	0.56
253	12	0.0180	26.3	457.06	26.71	17.11	5.72	261.26	92.55	0.66
254	12	0.0241	29.8	457.06	40.92	11.17	6.70	306.21	69.12	0.61
255	12	0.0306	33.2	457.06	58.20	7.85	7.66	350.31	54.30	0.58
256	12	0.0377	36.7	457.06	78.34	5.83	8.60	393.26	44.15	0.55
257	14	0.0043	21.6	615.05	2.42	253.98	2.42	149.07	446.94	0.95
258	14	0.0083	23.5	615.05	7.18	85.66	3.31	203.38	232.96	0.77
259	14	0.0133	25.5	615.05	15.64	39.33	4.26	261.95	146.04	0.61
260	14	0.0191	30.1	615.05	26.02	23.64	5.09	312.81	101.81	0.51
261	14	0.0250	32.4	615.05	40.37	15.24	5.97	366.90	77.66	0.49
262	14	0.0324	35.5	615.05	60.58	10.15	6.95	427.22	59.86	0.49
263	14	0.0393	38.4	615.05	81.32	7.56	7.78	478.29	49.30	0.39
264	20	0.0051	27.3	1226.42	2.59	473.72	2.08	255.03	539.85	1.00
265	20	0.0098	30.8	1226.42	7.43	164.70	2.72	334.10	282.23	0.73
266	20	0.0134	36.1	1226.42	14.65	83.74	3.33	408.40	179.65	0.52
267	20	0.0223	43.4	1226.42	24.34	50.38	3.92	480.73	124.36	0.39

Table 2D. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Plug Disc Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
276	2	0.0032	15.3	16.03	2.04	7.85	7.67	12.29	85.53	0.76
277	2	0.0060	15.1	16.03	6.19	2.59	11.90	19.09	46.17	0.62
278	2	0.0089	15.5	16.03	12.29	1.30	15.79	25.31	31.19	0.52
279	2	0.0131	15.3	16.03	25.52	0.63	21.45	34.40	21.13	0.51
280	2	0.0170	15.7	16.03	40.34	0.40	26.06	41.79	16.31	0.44
281	2	0.0222	15.9	16.03	66.01	0.24	32.19	51.61	12.47	0.47
282	2	0.0275	17.8	16.03	88.41	0.18	36.51	58.54	10.08	0.66
283	4	0.0036	16.0	56.82	2.33	24.34	5.03	28.60	154.53	0.43
284	4	0.0065	15.5	56.82	6.94	8.19	7.54	42.85	85.42	0.52
285	4	0.0100	16.1	56.82	14.78	3.84	10.15	57.69	55.23	0.54
286	4	0.0140	16.3	56.82	27.02	2.10	12.96	73.65	39.60	0.48
287	4	0.0187	16.5	56.82	46.05	1.23	16.16	91.80	29.60	0.43
288	4	0.0240	17.9	56.82	67.96	0.84	19.02	108.05	23.07	0.50
289	4	0.0297	22.2	56.82	82.24	0.69	20.61	117.10	18.65	0.60
290	6	0.0037	16.8	121.22	2.34	51.73	3.89	47.10	225.01	0.88
291	6	0.0069	17.4	121.22	6.95	17.43	5.68	68.82	120.04	0.68
292	6	0.0107	18.0	121.22	14.82	8.18	7.55	91.47	77.86	0.58
293	6	0.0153	19.4	121.22	26.96	4.50	9.54	115.60	41.71	0.50
294	6	0.0203	21.0	121.22	42.31	2.87	11.43	138.52	40.86	0.51
295	6	0.0260	23.2	121.22	61.19	1.98	13.28	161.03	31.91	0.55
296	6	0.0341	25.6	121.22	92.85	1.31	15.78	191.32	24.37	0.51
297	8	0.0039	17.2	208.70	2.52	82.80	3.34	69.74	284.02	0.77
298	8	0.0075	19.8	208.70	7.04	29.65	4.69	97.98	148.03	0.59
299	8	0.0120	22.2	208.70	15.01	13.90	6.17	128.80	92.01	0.52
300	8	0.0163	23.4	208.70	25.16	8.30	7.50	156.60	67.80	0.51
301	8	0.0231	25.7	208.70	44.00	4.74	9.34	194.85	47.91	0.49
302	8	0.0289	28.8	208.70	60.12	3.47	10.57	220.71	38.30	0.51

Table 2D. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Plug Disc Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
303	8	0.0330	32.2	208.70	69.16	3.02	11.19	233.53	33.59	0.55
304	10	0.0043	21.2	319.58	2.39	133.62	2.89	92.47	324.64	0.81
305	10	0.0081	23.7	319.58	6.84	46.74	4.02	128.42	170.16	0.63
306	10	0.0133	26.0	319.58	15.34	20.83	5.32	170.01	104.30	0.54
307	10	0.0184	29.5	319.58	24.91	12.83	6.36	203.24	75.22	0.48
308	10	0.0251	31.4	319.58	42.07	7.60	7.76	248.09	55.18	0.48
309	10	0.0315	34.0	319.58	60.05	5.32	8.92	285.10	43.93	0.43
310	12	0.0045	22.3	453.64	2.49	182.10	2.65	120.23	370.05	0.78
311	12	0.0088	25.0	453.64	7.47	60.73	3.69	167.27	188.92	0.55
312	12	0.0138	27.4	453.64	15.58	29.12	4.72	214.32	120.68	0.46
313	12	0.0195	31.8	453.64	25.65	17.68	5.65	256.20	85.41	0.41
314	12	0.0261	36.0	453.64	39.50	11.48	6.63	300.73	63.71	0.39
315	14	0.0047	26.3	610.41	2.29	266.10	2.39	146.17	411.65	0.80
316	14	0.0091	30.7	610.41	6.44	94.74	3.21	195.69	213.31	0.58
317	14	0.0150	33.2	610.41	15.08	40.47	4.22	257.47	129.08	0.48

Table 2E. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Composition Disc Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
327	2	0.0031	16.5	16.66	1.76	9.46	7.14	11.89	89.69	0.70
328	2	0.0057	16.3	16.66	5.68	3.16	10.99	18.31	48.65	1.14
329	2	0.0086	17.2	16.66	10.63	1.57	14.63	24.38	32.08	1.02
330	2	0.0129	17.1	16.66	22.37	0.74	19.97	33.27	21.49	0.82
331	2	0.0165	17.0	16.57	35.57	0.47	24.36	40.37	16.80	0.75
332	2	0.0209	16.9	16.57	55.53	0.30	29.46	48.83	13.31	0.66
333	2	0.0274	16.6	16.57	94.88	0.17	37.11	61.50	10.13	0.79
334	4	.0031	16.4	58.37	1.77	32.95	4.53	26.41	179.05	0.26
335	4	.0061	17.0	58.37	5.75	10.15	6.94	40.55	90.40	0.75
336	4	.0098	17.3	58.37	13.21	4.42	9.60	56.05	56.68	0.63
337	4	.0132	17.6	58.37	22.67	2.57	11.94	69.66	41.92	0.62
338	4	.0171	18.3	58.37	35.17	1.66	14.29	83.39	32.45	0.74
339	4	.0294	18.7	58.37	61.12	0.95	17.98	104.97	23.93	0.90
340	4	0.0294	20.3	58.37	88.74	0.66	21.04	122.82	18.85	0.97
341	6	0.0035	17.6	123.54	2.04	60.59	3.69	45.59	238.05	1.30
342	6	0.0065	17.2	123.54	6.23	19.83	5.42	66.93	128.85	1.15
343	6	0.0101	16.8	123.54	14.47	8.54	7.42	91.68	82.20	0.97
344	6	0.0141	18.5	123.54	24.27	5.09	9.08	112.16	58.99	0.95
345	6	0.0190	20.0	123.54	39.30	3.14	11.01	135.98	43.75	1.00
346	6	0.0256	23.5	123.54	58.87	2.10	12.97	160.28	32.46	0.99
347	6	0.0317	25.2	123.54	82.45	1.50	14.91	184.14	26.23	0.93
348	8	0.0037	17.2	211.79	2.33	90.89	3.25	68.76	298.05	1.22
349	8	0.0069	19.4	211.79	6.24	33.92	4.48	94.89	160.53	0.91
350	8	0.0115	20.4	211.79	15.19	13.94	6.61	130.57	96.05	0.78
351	8	0.0157	21.4	211.79	25.61	8.27	7.51	159.11	70.68	0.81
352	8	0.0125	23.3	211.79	42.55	4.98	9.16	193.99	51.58	0.78
353	8	0.0269	25.5	211.79	59.31	3.57	10.46	221.45	41.29	0.92
354	8	0.0353	27.0	211.79	94.55	2.24	12.63	266.52	31.41	0.81

Table 2E. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Composition Disc Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
355	10	0.0039	19.9	323.05	2.18	148.12	2.81	90.74	356.08	1.03
356	10	0.0075	25.0	323.05	6.81	47.47	4.00	129.15	185.58	0.76
357	10	0.0122	23.9	323.05	14.55	22.21	5.20	168.00	112.80	0.72
358	10	0.0170	25.4	323.05	25.12	12.86	6.35	205.25	81.45	0.68
359	10	0.0224	27.6	323.05	38.69	8.35	7.49	241.82	61.98	0.74
360	10	0.0296	30.9	323.05	59.03	5.47	8.82	285.03	46.78	0.75
361	10	0.0360	32.6	323.05	81.36	3.97	10.02	323.74	38.49	0.64
362	12	0.0041	19.2	457.06	2.47	184.69	2.64	120.67	405.86	1.04
363	12	0.0079	21.0	457.06	7.29	62.67	3.65	166.84	211.47	0.69
364	12	0.0121	23.5	457.06	14.39	31.75	4.58	209.51	137.34	0.62
365	12	0.0177	32.9	457.06	20.88	21.89	5.23	238.92	93.94	0.67
366	12	0.0245	33.9	457.06	37.50	12.19	6.48	296.29	67.83	0.69
367	12	0.0305	34.4	457.06	56.21	8.13	7.56	345.63	54.44	0.62
368	12	0.0384	20.9	457.06	143.57	3.18	10.95	500.52	43.30	0.30
369	14	0.0043	23.7	614.00	2.14	286.57	2.35	144.25	456.01	1.06
370	14	0.0082	25.2	614.00	6.62	92.80	3.23	198.09	235.44	0.79
371	14	0.0129	27.3	614.00	13.94	44.05	4.10	251.69	150.34	0.56
372	14	0.0179	30.6	614.00	22.98	26.72	4.87	298.97	108.23	0.48
373	14	0.0255	34.7	614.00	39.55	15.53	5.92	363.74	76.00	0.47
374	14	0.0307	37.1	614.00	52.61	11.67	6.59	404.58	63.19	0.48
375	14	0.0389	38.6	614.00	79.67	7.71	7.72	474.01	49.87	0.40
376	20	0.0051	29.6	1226.42	2.36	518.86	2.04	249.79	544.15	1.03
377	20	0.0098	32.9	1226.42	6.90	177.82	2.67	327.19	284.20	0.83
378	20	0.0155	36.8	1226.42	14.63	83.85	3.31	408.24	178.30	0.54

Table 2F. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Composition Disc Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
387	2	0.0032	14.7	16.62	2.10	7.91	7.64	12.70	86.06	1.65
388	2	0.0061	15.2	16.62	6.24	2.66	11.77	19.56	45.79	1.21
389	2	0.0097	15.1	16.62	14.47	1.15	16.65	27.67	28.92	0.95
390	2	0.0128	15.0	16.62	24.90	0.67	20.91	34.75	21.63	0.83
391	2	0.0168	15.4	16.62	40.05	0.41	25.59	42.53	16.53	0.72
392	2	0.0224	16.7	16.62	63.93	0.26	31.27	51.96	12.36	0.83
393	2	0.0268	16.9	16.62	88.59	0.19	35.98	59.79	10.34	1.02
394	4	0.0031	14.7	58.48	1.97	29.66	4.69	27.45	178.45	0.57
395	4	0.0062	14.9	58.48	6.55	8.93	7.32	42.81	89.50	0.72
396	4	0.0096	15.8	58.48	13.83	4.23	9.77	57.15	57.84	0.57
397	4	0.0133	16.5	58.48	24.15	2.42	12.23	71.56	41.78	0.63
398	4	0.0173	18.1	58.60	36.23	1.62	14.40	84.38	32.00	0.77
399	4	0.0233	17.7	58.60	64.52	0.91	18.37	107.63	23.86	0.73
400	4	0.0285	19.5	58.60	85.82	0.68	20.71	121.37	19.48	0.98
401	6	0.0035	16.5	124.12	2.11	58.92	3.72	46.22	240.82	1.29
402	6	0.0064	18.4	124.12	5.68	21.84	5.23	64.94	129.82	0.85
403	6	0.0105	18.9	124.12	13.59	9.13	7.23	89.77	79.29	0.89
404	6	0.0150	20.4	124.12	24.40	5.09	9.08	112.72	55.51	0.89
405	6	0.0204	21.9	124.12	40.53	3.06	11.12	138.07	40.79	0.86
406	6	0.0254	23.3	124.12	57.72	2.15	12.84	159.42	32.77	0.92
407	6	0.0321	26.0	124.12	80.79	1.54	14.75	183.10	25.95	0.86
408	8	0.0038	17.9	213.50	2.32	91.68	3.24	69.02	289.84	1.28
409	8	0.0070	18.7	213.22	6.57	32.38	4.55	97.07	158.14	0.88
410	8	0.0110	22.3	213.22	12.84	16.65	5.77	123.10	99.83	0.79
411	8	0.0160	23.8	213.22	23.68	9.01	7.27	155.03	69.26	0.75
412	8	0.0215	24.3	213.22	40.21	5.30	8.93	190.50	51.70	0.68
413	8	0.0273	25.8	213.22	59.97	3.56	10.47	223.33	40.59	0.68

Table 2F. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Composition Disc Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
414	8	0.0349	27.8	213.22	89.04	2.39	12.29	262.09	31.76	0.75
415	10	0.0046	19.5	325.64	2.97	109.65	3.07	99.88	300.83	0.97
416	10	0.0077	23.0	325.64	7.19	45.28	4.06	132.26	179.96	0.70
417	10	0.0124	21.9	325.64	16.06	20.28	5.37	174.99	111.49	0.57
418	10	0.0169	25.2	325.64	24.63	13.22	6.29	204.77	82.22	0.64
419	10	0.0225	26.4	325.64	40.40	8.06	7.59	241.07	61.71	0.67
420	10	0.0298	29.9	325.64	60.93	5.34	8.91	290.02	46.58	0.61
421	10	0.0376	34.1	325.64	83.54	3.90	10.10	328.74	36.90	0.63
422	12	0.0042	20.0	461.33	2.45	188.28	2.63	121.15	396.56	0.99
423	12	0.0081	23.8	461.33	6.71	68.80	3.54	163.43	205.64	0.68
424	12	0.0128	26.3	461.33	14.08	32.76	4.53	209.20	129.87	0.57
425	12	0.0183	28.6	461.33	25.11	18.37	5.57	256.92	91.13	0.57
426	12	0.0239	29.8	461.33	40.05	11.51	6.62	305.49	69.78	0.55
427	12	0.0316	34.1	461.33	59.84	7.71	7.72	356.12	52.68	0.55
428	12	0.0394	36.1	461.33	86.48	5.33	8.91	411.16	42.23	0.49
429	14	0.0044	21.4	619.67	2.48	249.90	2.43	150.82	442.41	0.99
430	14	0.0085	24.2	619.67	7.15	86.63	3.29	204.19	229.47	0.66
431	14	0.0134	26.9	619.67	14.99	41.35	4.19	259.49	145.02	0.48
432	14	0.0190	30.3	619.67	25.57	24.23	5.04	312.37	102.30	0.42
433	14	0.0254	34.6	619.67	38.88	15.94	5.87	363.57	76.44	0.43
434	14	0.0332	36.6	619.67	61.22	10.12	6.95	430.93	58.44	0.44
435	14	0.0413	40.2	619.67	85.08	7.29	7.89	488.91	47.00	0.37
436	20	0.0051	26.1	1232.70	2.67	461.11	2.09	257.94	541.83	0.98
437	20	0.0095	31.4	1232.68	6.71	181.57	2.65	326.97	292.44	0.80

Table 2G. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Bevel Seat Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
446	2	0.0033	15.4	16.74	2.10	7.97	7.62	12.76	83.53	1.63
447	2	0.0057	15.1	16.74	5.89	2.84	11.47	19.20	47.28	1.40
448	2	0.0090	15.5	16.74	12.45	1.34	15.59	26.10	30.86	0.87
449	2	0.0124	15.3	16.74	22.74	0.74	20.06	33.59	22.41	0.88
450	2	0.0168	15.7	16.74	39.25	0.43	25.29	42.35	16.49	0.83
451	2	0.0212	17.25	16.74	55.37	0.30	29.30	49.06	13.07	0.81
452	2	0.0274	16.75	16.74	92.35	0.18	36.52	61.14	10.14	0.88
453	4	0.0034	14.37	58.60	2.42	24.24	5.04	29.54	160.44	0.93
454	4	0.0064	14.16	58.60	7.38	7.94	7.61	44.72	86.49	0.76
455	4	0.0097	17.08	58.60	13.06	4.48	9.54	55.94	57.02	0.60
456	4	0.0135	17.45	58.60	23.30	2.52	12.05	70.60	41.21	0.69
457	4	0.0174	17.05	58.60	38.43	1.52	14.80	86.72	31.92	0.78
458	4	0.0229	18.72	58.60	58.98	0.99	17.69	103.65	24.22	0.78
459	4	0.0294	19.74	58.60	89.86	0.65	21.12	123.76	18.88	0.84
460	6	0.0035	17.00	123.92	2.10	58.93	3.72	46.14	236.73	1.29
461	6	0.0065	18.30	123.92	5.81	21.32	5.00	61.96	127.47	1.04
462	6	0.0103	18.86	123.92	13.11	9.45	7.14	88.45	80.88	0.91
463	6	0.0150	19.49	123.92	25.53	4.85	9.25	114.65	55.46	0.80
464	6	0.0194	20.91	123.92	38.75	3.20	10.93	135.46	42.77	0.89
465	6	0.0252	22.40	123.92	59.20	2.09	12.99	160.94	32.98	0.89
466	6	0.0317	23.97	123.92	85.52	1.45	15.11	187.29	26.25	0.84
467	8	0.0038	17.91	212.68	2.32	91.62	3.24	68.88	289.44	1.28
468	8	0.0071	17.77	212.68	7.05	30.16	4.67	99.26	156.27	0.81
469	8	0.0117	20.34	212.68	15.43	13.78	6.19	131.67	94.67	0.70
470	8	0.0160	21.86	212.68	25.76	8.25	7.52	159.90	69.14	0.69
471	8	0.0215	24.11	212.68	40.51	5.25	8.97	190.75	51.61	0.77
472	8	0.0272	25.43	212.68	60.10	3.54	10.49	223.19	40.78	0.79
473	8	0.0341	26.97	212.68	87.13	2.44	12.20	259.41	32.57	0.72

Table 2G. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Bevel Seat Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
474	10	0.0040	18.54	324.16	2.42	133.93	2.89	93.73	346.42	1.07
475	10	0.0077	21.30	324.16	6.85	47.33	4.00	129.72	179.60	0.75
476	10	0.0119	23.81	324.16	13.58	23.88	5.07	164.27	116.41	0.68
477	10	0.0169	25.35	324.16	24.47	13.24	6.28	203.70	82.05	0.60
478	10	0.0225	26.32	324.16	40.50	8.00	7.61	246.63	61.58	0.69
479	10	0.0294	28.89	324.16	61.14	5.30	8.93	289.61	47.23	0.61
480	10	0.0368	32.69	324.16	83.31	3.89	10.10	327.49	37.69	0.62
481	12	0.0042	17.15	458.84	2.81	163.45	2.73	125.33	399.46	0.88
482	12	0.0080	19.76	458.84	7.96	57.67	3.75	172.05	206.81	0.64
483	12	0.0125	22.43	458.84	15.67	29.28	4.72	216.36	133.50	0.50
484	12	0.0180	25.52	458.84	27.49	16.69	5.77	264.69	92.20	0.55
485	12	0.0244	29.82	458.84	41.70	11.00	6.74	309.15	68.12	0.55
486	12	0.0308	34.44	458.84	56.06	8.18	7.54	346.10	54.10	0.51
487	12	0.0373	35.81	458.84	78.14	5.87	8.58	393.80	44.59	0.49
489	14	0.0044	19.71	616.62	2.69	229.28	2.49	153.53	441.38	0.81
490	14	0.0082	22.20	616.62	7.28	84.64	3.32	204.66	237.52	0.64
491	14	0.0132	25.92	616.62	15.00	41.09	4.20	258.75	147.46	0.47
492	14	0.0185	29.43	616.62	24.94	24.72	5.00	308.63	105.00	0.41
493	14	0.0244	34.69	616.62	35.85	17.20	5.70	351.79	79.46	0.44
494	14	0.0310	41.81	616.62	47.05	13.10	6.31	389.02	62.49	0.50
495	14	0.0398	46.36	616.62	68.39	9.02	7.27	448.15	48.75	0.43

Table 2H. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Bevel Seat Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
504	2	0.0033	15.61	16.36	2.10	7.80	7.68	12.57	83.02	2.34
505	2	0.0062	15.57	16.36	6.26	2.61	11.87	19.41	44.95	1.45
506	2	0.0096	15.51	16.36	14.08	1.16	16.57	27.10	28.85	1.03
507	2	0.0131	15.94	16.36	24.47	0.67	20.90	34.18	21.08	0.85
508	2	0.0169	16.78	16.36	37.52	0.44	25.05	40.99	16.31	0.86
509	2	0.0222	19.50	16.36	53.77	0.30	29.22	47.81	12.44	1.03
510	2	0.0276	19.30	16.36	81.47	0.20	34.94	57.16	10.06	0.99
511	4	0.0035	14.31	57.52	2.43	23.68	5.08	29.23	160.39	0.92
512	4	0.0065	16.88	57.52	6.33	9.08	7.25	41.69	85.41	0.70
513	4	0.0103	16.73	57.52	14.78	3.89	10.10	58.11	53.91	0.52
514	4	0.0140	17.40	57.52	25.28	2.27	12.55	72.20	39.50	0.60
515	4	0.0184	17.86	57.52	41.05	1.40	15.33	88.15	30.07	0.77
516	4	0.0231	18.66	57.52	60.18	0.96	17.98	103.40	24.00	0.70
517	4	0.0294	20.24	57.52	87.66	0.66	21.06	121.15	18.87	0.73
518	6	0.0037	16.30	122.09	2.35	51.98	3.88	47.37	227.70	1.29
519	6	0.0068	17.11	122.09	6.79	17.98	5.61	68.54	122.32	0.91
520	6	0.0109	16.81	122.09	16.42	7.43	7.83	95.57	76.18	0.70
521	6	0.0149	19.30	122.09	25.36	4.81	9.28	113.32	55.94	0.79
522	6	0.0196	20.31	122.09	40.54	3.01	11.20	136.74	42.40	0.78
523	6	0.0254	21.29	122.09	63.17	1.93	13.41	163.83	32.73	0.77
524	6	0.0319	23.61	122.09	87.91	1.39	15.38	187.80	26.08	0.82
525	8	0.0038	17.95	210.12	2.27	92.47	3.23	67.86	292.93	1.06
526	8	0.0073	18.67	210.12	7.09	29.65	4.69	98.64	151.81	0.75
527	8	0.0119	21.24	210.12	15.23	13.80	6.19	130.04	93.21	0.65
528	8	0.0163	22.63	210.12	25.62	8.20	7.54	158.38	68.13	0.68
529	8	0 0240	24.76	210.12	48.71	4.31	9.70	203.72	46.21	0.68
530	8	0.0275	26.22	210.12	59.71	3.52	10.52	221.00	40.30	0.73

Table 2H. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Bevel Seat Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
531	8	0.0344	27.84	210.12	86.22	2.44	12.20	256.44	32.23	0.65
532	10	0.0042	18.11	320.91	2.66	120.60	2.98	95.68	333.12	1.14
533	10	0.0078	19.90	320.91	7.45	43.07	4.13	132.54	178.18	0.79
534	10	0.0125	22.53	320.91	15.82	20.29	5.37	172.41	110.54	0.62
535	10	0.0170	24.82	320.91	25.34	12.67	6.39	205.06	81.53	0.65
536	10	0.0233	25.79	320.91	44.31	7.24	7.91	253.78	59.41	0.68
537	10	0.0299	29.40	320.91	62.59	5.13	9.05	290.52	46.27	0.61
538	10	0.0267	33.95	320.91	80.25	4.00	9.99	320.67	37.71	0.59
539	12	0.0042	20.78	455.27	2.36	192.05	2.61	118.74	395.99	0.99
540	12	0.0079	23.68	455.27	6.45	70.55	3.51	159.99	210.30	0.65
541	12	0.0127	26.29	455.63	13.91	32.75	4.54	206.64	130.86	0.51
542	12	0.0181	30.29	455.27	23.44	19.42	5.46	248.50	91.71	0.56
543	12	0.0246	31.54	455.27	40.25	11.31	6.67	303.55	67.45	0.54
544	12	0.0310	34.01	455.27	57.86	7.87	7.66	348.67	53.61	0.50
545	12	0.0378	38.61	455.27	74.43	6.12	8.45	384.52	44.02	0.47
546	14	0.0044	21.97	612.03	2.45	249.63	2.44	149.01	437.96	1.02
547	14	0.0086	24.47	612.03	7.28	84.09	3.32	203.54	225.91	0.76
549	14	0.0134	26.38	612.03	15.28	40.04	4.23	259.08	144.79	0.52
549	14	0.0187	28.89	612.03	25.98	23.56	5.09	311.64	103.87	0.44
550	14	0.0255	34.11	612.03	39.81	15.37	5.95	363.89	75.95	0.44
551	14	0.0320	38.46	612.03	54.48	11.23	6.68	409.13	60.52	0.43
552	14	0.0396	42.92	612.03	73.31	8.35	7.49	458.15	48.99	0.40

Table 2I. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gas Line Cock Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L x10^4$ psi./ft.	$(\Delta P/\Delta L)_G x10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} x10^3$ psi./ft.	W_L/W_G	ψ
562	2	0.0033	15.36	16.84	2.11	7.99	7.61	12.83	83.77	1.66
563	2	0.0061	16.45	16.84	5.76	2.92	11.34	19.09	45.82	1.11
564	2	0.0091	17.21	16.84	11.57	1.46	15.08	25.41	30.45	0.99
565	2	0.0128	17.11	16.84	21.83	.77	19.67	33.13	21.65	0.86
566	2	0.0170	16.91	16.84	37.25	.45	24.67	41.55	16.36	0.95
567	2	0.0216	16.78	16.84	59.19	.28	30.07	50.65	12.85	0.87
568	2	0.0275	16.90	16.84	93.08	.18	36.55	61.55	10.09	1.14
569	4	0.0032	16.21	58.82	1.92	30.71	4.64	27.28	171.64	0.87
570	4	0.0062	16.91	58.82	5.77	10.19	6.94	40.80	90.13	0.98
571	4	0.0100	16.82	58.82	14.14	4.16	9.84	57.86	55.25	0.78
572	4	0.0137	16.90	58.82	25.06	2.35	12.39	72.90	40.44	0.86
573	4	0.0179	16.95	58.82	40.99	1.44	15.17	89.26	31.04	1.01
574	4	0.0224	17.72	58.82	60.25	.98	17.82	104.81	24.72	0.95
575	4	0.0295	18.95	58.82	94.98	.62	21.58	126.97	18.79	1.19
576	6	0.0036	15.60	124.41	2.35	52.98	3.86	47.96	233.86	1.32
577	6	0.0066	16.25	124.41	6.73	18.49	5.56	69.12	126.95	1.13
578	6	0.0108	16.75	124.41	16.20	7.68	7.73	96.19	77.13	1.07
579	6	0.0147	17.44	124.41	27.61	4.51	9.53	118.55	56.62	0.97
580	6	0.0199	18.83	124.41	45.12	2.76	11.61	144.39	41.84	1.03
581	6	0.0255	21.35	124.41	63.88	1.95	13.38	166.42	32.59	1.04
582	6	0.0320	23.76	124.41	88.43	1.41	15.30	190.35	25.99	1.11
583	8	0.0037	17.91	213.22	2.23	95.48	3.20	68.19	297.19	1.60
584	8	0.0071	18.76	213.25	6.81	31.30	4.61	98.24	155.26	1.02
585	8	0.0111	18.74	213.22	15.25	13.98	6.16	131.30	100.00	0.93
586	8	0.0161	20.81	213.22	27.49	7.76	7.70	164.19	68.84	0.83
587	8	0.0214	24.01	213.22	40.72	5.24	8.98	191.43	51.78	0.98
588	8	0.0275	26.33	213.22	49.48	3.58	10.44	222.60	40.41	1.01

Table 21. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gas Line Cock Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L x10^4$ psi./ft.	$(\Delta P/\Delta L)_G x10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} x10^3$ psi./ft.	W_L/W_G	ψ
589	8	0.0343	29.99	213.22	80.26	2.66	11.78	251.24	32.32	0.96
590	10	0.0039	19.62	325.26	2.25	144.51	2.83	92.01	351.65	1.27
591	10	0.0075	20.38	325.26	6.84	47.57	4.00	129.94	185.23	0.86
592	10	0.0119	21.78	325.26	14.87	21.88	5.23	170.05	116.94	0.80
593	10	0.0173	25.01	325.26	26.14	12.44	6.43	209.23	80.21	0.84
594	10	0.0228	28.48	325.26	38.81	8.38	7.47	243.12	60.73	0.82
595	10	0.0297	31.79	325.26	57.34	5.67	8.70	282.97	46.70	0.82
596	10	0.0363	35.25	325.26	75.91	4.28	9.72	316.20	38.23	0.81
597	12	0.0041	20.10	459.87	2.40	191.53	2.61	120.20	401.21	1.19
598	12	0.0077	21.81	459.87	6.70	68.62	3.55	163.05	216.43	0.85
599	12	0.0125	25.33	459.87	14.08	32.65	4.54	208.77	133.13	0.71
600	12	0.0180	27.57	459.87	25.48	18.05	5.61	257.80	92.61	0.70
601	12	0.0239	30.84	459.87	39.14	11.75	6.57	302.25	69.55	0.70
602	12	0.0309	33.11	459.87	59.47	7.73	7.71	354.56	53.81	0.68
603	12	0.0376	36.46	459.87	78.58	5.85	8.59	395.20	44.26	0.68
604	14	0.0043	20.63	617.73	2.50	247.38	2.44	150.76	451.10	1.08
605	14	0.0081	24.47	617.73	6.62	93.29	3.22	198.97	238.56	0.94
606	14	0.0133	26.88	617.73	14.84	41.63	4.18	258.09	146.23	0.59
607	14	0.0189	29.87	617.73	25.96	23.80	5.07	313.42	102.51	0.64
608	14	0.0253	33.44	617.73	40.25	15.35	5.95	367.53	76.60	0.55
609	14	0.0322	37.01	617.73	57.63	10.72	6.80	420.33	60.20	0.48
610	14	0.0383	41.51	617.73	71.65	8.62	7.39	456.74	60.54	0.48
611	20	0.0051	26.91	1230.64	2.60	474.00	2.08	255.88	543.05	1.28
612	20	0.0098	31.36	1230.64	7.23	170.26	2.70	332.32	283.62	0.97

Table 2J. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gas Line Cock Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
621	2	0.0033	15.21	16.25	2.13	7.63	7.75	12.60	83.63	0.99
622	2	0.0064	16.01	16.25	6.54	2.49	12.10	19.67	43.30	0.86
623	2	0.0097	15.83	16.25	14.11	1.15	16.63	27.03	28.57	0.78
624	2	0.0131	16.70	16.25	23.37	0.70	20.54	33.40	21.11	0.71
625	2	0.0170	16.40	16.25	38.40	0.42	25.38	41.24	16.33	0.76
626	2	0.0227	16.66	16.25	65.20	0.25	31.83	51.74	12.24	0.72
627	2	0.0275	17.01	16.25	92.48	0.18	37.01	60.15	10.07	0.65
628	4	0.0035	15.94	57.31	2.18	26.26	4.90	28.08	160.66	0.61
629	4	0.0065	16.50	57.30	6.48	8.84	7.32	41.97	85.54	0.66
630	4	0.0103	16.30	57.30	15.18	3.78	10.23	58.60	53.99	0.51
631	4	0.0142	16.91	57.30	26.52	2.16	12.82	73.46	39.17	0.52
632	4	0.0184	17.24	57.30	42.55	1.35	15.58	89.28	30.11	0.63
633	4	0.0242	18.48	57.30	66.81	0.86	18.81	107.81	22.89	0.70
634	4	0.0314	20.82	57.30	97.31	0.59	22.05	126.36	17.64	0.73
635	6	0.0036	16.11	121.76	2.33	52.31	3.87	47.14	231.16	0.83
636	6	0.0068	17.05	121.72	6.82	17.84	5.63	68.52	122.59	0.51
637	6	0.0106	17.29	121.72	15.15	8.03	7.60	92.48	78.58	0.58
638	6	0.0155	19.68	121.72	26.98	4.51	9.52	115.93	53.69	0.58
639	6	0.0203	21.92	121.72	40.52	3.00	11.21	136.45	40.84	0.63
640	6	0.0264	24.02	121.72	60.63	2.01	13.21	160.81	31.47	0.68
641	6	0.0334	26.54	121.72	85.79	1.42	15.25	185.58	24.91	0.63
642	8	0.0039	18.29	209.69	2.37	88.50	3.27	68.64	283.92	0.87
643	8	0.0074	20.90	209.69	6.45	32.52	4.55	95.33	150.72	0.69
644	8	0.0120	23.38	209.69	14.25	14.71	6.04	126.71	91.98	0.58
645	8	0.0167	25.55	209.69	23.99	8.74	7.36	154.23	66.31	0.61
646	8	0.0228	27.84	209.69	39.70	5.28	8.95	187.63	48.51	0.57
647	8	0.0289	29.95	209.69	57.81	3.63	10.39	217.89	38.32	0.59
648	8	0.0366	33.22	209.69	82.05	2.56	11.97	251.01	30.25	0.57

Table 2J. Data and Results for Co-Current Flow of Air and Water in 1 Inch Pipe 194 Inches Long with Gas Line Cock Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	P_{AVG} psia.	$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	X^2	ϕ^2	$(\Delta P/\Delta L)_{TP} \times 10^3$ psi./ft.	W_L/W_G	ψ
650	10	0.0041	19.58	320.27	2.42	132.17	2.90	92.96	337.15	0.82
651	10	0.0081	24.11	320.27	6.72	47.65	3.99	127.88	170.21	0.63
652	10	0.0128	25.52	320.27	14.71	21.77	5.24	167.76	107.78	0.54
653	10	0.0180	27.79	320.27	25.28	12.67	6.39	204.63	77.07	0.51
654	10	0.0244	30.85	320.27	40.77	7.86	7.66	245.42	56.64	0.51
655	10	0.0300	33.36	320.27	55.74	5.75	8.66	277.22	46.14	0.48
656	12	0.0043	22.77	454.08	2.30	197.60	2.59	117.68	382.79	0.82
657	12	0.0083	25.57	454.08	6.51	69.72	3.53	160.18	201.17	0.57
658	12	0.0131	28.33	454.08	13.51	33.61	4.49	204.10	126.78	0.43
659	12	0.0185	30.35	454.08	24.48	18.55	5.55	252.03	89.76	0.42
660	12	0.0251	33.61	454.08	39.30	11.55	6.61	300.34	66.23	0.39
661	14	0.0047	25.94	610.88	2.33	262.52	2.40	146.79	412.06	0.78
662	14	0.0090	27.59	610.88	7.01	87.13	3.29	200.94	216.20	0.56
663	14	0.0136	30.49	610.88	13.69	44.61	4.08	249.35	142.47	0.43
664	14	0.0195	33.85	610.88	24.10	25.35	4.96	303.05	99.64	0.36
665	14	0.0258	35.22	610.88	39.65	15.41	5.94	362.93	75.02	0.31

CHAPTER V

CONCLUSIONS

The conclusions resulting from the present investigation may be summarized as follow:

1. A continuation of the work by Sharp (1) in 1 1/2 inch pipe has been completed using 1 inch pipe, and a more complete correlation has been proposed. This new correlation is ψ expressed as a function of X^2, the ratio of the pressure drop for the flow of the liquid alone to the pressure drop for the flow of the gas alone.

2. This correlation is accurate within ± 40 per cent for both 1 and 1 1/2 inch valves.

APPENDICES

APPENDIX I

IDENTIFICATION OF VALVES USED IN TESTS

The following 1 inch valves were generously donated by the Crane Company for use in the two-phase pressure drop evaluations:

Valve	Crane Catalogue No.
1. 150-Pound Brass Globe Valve with Cranite Composition Disc	7
2. 150-Pound Bronze Globe Valve, Plug Disc Type	14 1/2P
3. 200-Pound Bronze Globe Valve, Regrinding (Bevel Seat)	70
4. 150-Pound Bronze Gate Valve, Wedge Disc-Rising Stem	431
5. 125-Pound Iron Gas Line Cock with Brass Plug	1232

APPENDIX II

BASIC DATA FROM ALL RUNS

Table 3 includes the basic experimental data from all runs made in these tests.

Table 3A. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Calibration Runs, No Valve

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to\ Test\ Section}$ psig.
1	2		22		0	0
2	4		22		0.14	0
3	6		22		0.39	0
4	8		22		0.69	1.0
5	10		22		1.12	1.5
6	12		22		1.47	2.0
7	14		22		2.04	4.0
8	20		22		4.83	6.0
9	30		22		11.79	12.5
10	2	0.0031	22	27	0.39	0
11	2	0.0056	22	27	1.12	0
12	2	0.0086	24	27	1.61	0
13	2	0.0125	24	27	1.69	0
14	2	0.0165	24	27	1.77	1.5
15	2	0.0208	24	27	2.02	1.0
16	2	0.0260	24	27	2.79	2.0
17	4	0.0032	25	27	1.79	0
18	4	0.0060	25.5	27	2.00	2.0
19	4	0.0094	25.5	27	2.38	2.0
20	4	0.0131	25.5	27	2.55	3.5
21	4	0.0178	25.5	27	3.30	5.0
22	4	0.0225	25.5	27	4.66	5.0
23	4	0.0285	25.5	27	5.09	5.5
24	6	0.0036	26.5	27	1.98	1.0
25	6	0.0065	26.5	27	2.42	3.5
26	6	0.0101	26.5	27	3.85	5.0
27	6	0.0138	26.5	27	5.09	6.0
28	6	0.0186	26.5	27	6.51	7.0
29	6	0.0245	26.5	27	7.94	8.0
30	6	0.0310	26.5	27	8.56	11.0
31	8	0.0037	27	27	4.11	3.5
32	8	0.0068	27	27	5.46	5.0
33	8	0.0107	27	27	6.09	5.5
34	8	0.0152	27	27	7.92	7.5
35	8	0.0203	27	27	9.59	9.0
36	8	0.0266	27	27	10.96	13.0
37	8	0.0342	27	27	13.00	14.0
38	10	0.0038	28	27	5.09	5.0
39	10	0.0073	28	27	5.85	7.0
40	10	0.0112	28	27	8.13	7.0

Table 3A. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Calibration Runs, No Valve

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp}$ in. Hg.	P_{inlet} to Test Section psig.
41	10	0.0165	28	27	9.59	9.0
42	10	0.0220	28	27	11.22	15.0
43	10	0.0283	28	27	13.04	17.0
44	10	0.0354	28	27	14.46	20.0
45	12	0.0041	28	27	6.09	6.0
46	12	0.0077	28	27	7.54	9.0
47	12	0.0127	28	27	8.37	12.0
48	12	0.0179	28	27	10.63	15.0
49	12	0.0245	28	27	12.73	17.0
50	12	0.0306	28	27	14.48	23.0
51	12	0.0382	28	27	16.64	25.0
52	14	0.0041	29.5	27	6.74	8.0
53	14	0.0078	29.5	27	7.78	10.0
54	14	0.0127	29.5	27	9.98	13.0
55	14	0.0181	29.5	27	11.43	15.0
56	14	0.0243	29.5	27	12.93	21.0
57	14	0.0311	29.5	27	15.99	25.0
58	14	0.0382	29.5	27	16.44	27.0
59	20	0.0049	30.5	27	12.16	13.0
60	20	0.0094	30.5	27	13.44	16.0
61	20	0.0146	30.5	27	14.28	20.0
62	20	0.0217	30.5	27	16.48	25.0
63	20	0.0285	30.5	27	16.95	30.0
64	20	0.0360	30.5	27	19.09	35.0
65	20	0.0443	30.5	27	20.72	38.0
66	30	0.0059	31	27	19.03	24.0
67	30	0.0110	31	27	20.43	28.0

Table 3B. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Gate Valve, Tapered Wedge, Rising Stem, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
68	2		23		0	0
69	4		23		0.15	0
70	6		23		0.40	0
71	8		23		0.70	1.0
72	10		23		1.10	1.2
73	12		23		1.50	1.8
74	14		23		2.10	2.2
75	20		23		4.93	5.2
76	30		23		11.95	11.8
77	2	0.0032	24	23	0.40	0
78	2	0.0059	24	23	1.20	0
79	2	0.0089	24	23	1.80	1.5
80	2	0.0123	24	23	1.80	2.0
81	2	0.0165	24	23	1.80	2.0
82	2	0.0214	24	23	2.17	2.0
83	2	0.0266	24	23	2.98	2.5
84	4	0.0032	26	22	1.80	2.0
85	4	0.0063	26	22	2.17	2.5
86	4	0.0095	26	22	2.39	3.0
87	4	0.0132	26	22	2.77	4.0
88	4	0.0172	26	22	3.56	5.0
89	4	0.0229	26	22	4.71	5.0
90	4	0.0280	27	22	5.50	5.0
91	6	0.0035	27	22	1.98	2.0
92	6	0.0063	27	22	2.39	3.5
93	6	0.0098	27	22	3.95	5.0
94	6	0.0140	27	22	6.09	7.0
95	6	0.0191	27	22	7.09	7.5
96	6	0.0247	27	22	8.63	8.0
97	6	0.0301	27	22	9.80	10.0
98	8	0.0037	27	22	4.71	3.0
99	8	0.0069	27	22	4.91	4.0
100	8	0.0108	27	22	6.50	6.0
101	8	0.0149	27	22	8.06	7.0
102	8	0.0201	27	22	10.59	7.5
103	8	0.0267	27	22	11.75	12.0
104	8	0.0335	27	22	13.09	14.0
105	10	0.0039	28	22	5.50	5.0
106	10	0.0071	28	22	6.09	6.5

Table 3B. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Gate Valve, Tapered Wedge, Rising Stem, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
107	10	0.0109	28	22	8.25	7.5
108	10	0.0163	28	22	9.60	8.0
109	10	0.0215	28	22	11.75	12.0
110	10	0.0284	28	22	13.87	14.0
111	10	0.0350	28	22	15.63	17.0
112	12	0.0040	29	22	6.69	5.0
113	12	0.0076	29	22	7.86	6.5
114	12	0.0119	29	22	9.01	9.0
115	12	0.0168	29	22	11.35	11.0
116	12	0.0231	29	22	12.70	14.0
117	12	0.0295	29	22	15.05	15.5
118	12	0.0368	29	22	17.22	16.0
119	14	0.0041	30	22	7.86	6.0
120	14	0.0078	30	22	8.25	7.5
121	14	0.0126	30	22	10.00	10.0
122	14	0.0180	30	22	11.72	13.0
123	14	0.0242	30	22	14.46	15.0
124	14	0.0310	30	22	16.60	19.0
125	14	0.0385	30	22	18.62	24.0
126	20	0.0049	30	22	12.50	12.0
127	20	0.0091	30	22	13.47	15.0
128	20	0.0145	30	22	14.46	17.0
129	20	0.0204	30	22	16.44	20.0
130	20	0.0283	30	22	17.22	25.0
131	20	0.0358	30	22	19.03	30.0
132	20	0.0432	30	22	21.01	35.0
133	30	0.0058	30	22	21.01	21.0
134	30	0.0109	30	22	22.20	25.0
135	30	0.0161	30	22	23.20	30.0

Table 3C. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Gate Valve, Tapered Wedge, Rising Stem, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to}$ Test Section psig.
136	2		30		0.25	0
137	4		30		0.52	0
138	6		30		0.80	0
139	8		30		1.12	0.60
140	10		30		1.51	1.50
141	12		30		2.00	2.0
142	14		30		2.61	2.4
143	20		30		5.50	6.7
144	30		30		12.90	12.1
147	2	0.0031	30	23	0.35	0
148	2	0.0056	30	23	1.20	0
149	2	0.0088	30	23	1.80	0
150	2	0.0125	30	23	1.80	0
151	2	0.0166	30	23	2.18	0
152	2	0.0208	30	23	2.98	1.0
153	2	0.0266	30	23	3.56	2.0
154	4	0.0032	31	23	1.80	1.0
155	4	0.0063	31	23	2.18	1.5
156	4	0.0094	31	23	2.58	2.0
157	4	0.0135	31	23	3.35	3.0
158	4	0.0174	31	23	3.94	3.5
159	4	0.0225	31	23	5.30	4.0
160	4	0.0283	31	23	6.10	5.0
161	6	0.0036	31	22	2.56	1.5
162	6	0.0068	31	22	3.15	3.0
163	6	0.0103	31	22	4.13	4.0
164	6	0.0143	31	22	6.50	4.5
165	6	0.0191	31	22	8.05	7.0
166	6	0.0241	31	22	9.02	8.0
167	6	0.0305	31	22	10.98	9.0
168	8	0.0037	31	22	4.35	2.5
169	8	0.0069	31	22	5.11	5.5
170	8	0.0106	31	22	6.50	6.0
171	8	0.0153	31	22	8.05	7.5
172	8	0.0203	31	22	9.41	9.0
173	8	0.0262	31	22	11.72	10.0
174	8	0.0337	31	22	13.67	12.5
175	10	0.0038	32	22	5.90	5.0
176	10	0.0074	32	22	6.90	6.0

Table 3C. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Gate Valve, Tapered Wedge, Rising Stem, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
177	10	0.0115	32	22	8.43	7.5
178	10	0.0162	32	22	9.41	8.5
179	10	0.0218	32	22	11.90	10.0
180	10	0.0289	32	22	14.46	12.0
181	10	0.0361	32	22	17.43	15.0
182	12	0.0040	32	22	6.69	5.0
183	12	0.0076	32	22	7.86	7.5
184	12	0.0122	32	22	9.21	9.0
185	12	0.0171	32	22	11.37	11.0
186	12	0.0228	32	22	13.47	14.0
187	12	0.0297	32	22	15.73	17.0
188	12	0.0366	32	22	18.05	20.0
189	14	0.0042	32	22	7.48	6.5
190	14	0.0078	32	22	8.82	8.0
191	14	0.0127	32	22	10.98	11.0
192	14	0.0186	32	22	12.70	14.0
193	14	0.0244	32	22	15.04	17.0
194	14	0.0312	32	22	17.43	20.0
195	14	0.0388	32	22	19.62	25.0
196	20	0.0046	32	22	12.50	11.0
197	20	0.0090	32	22	14.46	17.5
198	20	0.0148	32	22	15.82	20.0
199	20	0.0212	32	22	16.21	25.0
200	20	0.0278	32	22	17.83	30.0
201	20	0.0354	32	22	19.03	35.0
202	20	0.0444	32	22	21.60	38.0
203	30	0.0059	32	22	22.60	22.0
204	30	0.0112	32	22	24.40	27.0
205	30	0.0180	32	22	25.40	30.0

Table 3D. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Plug Disc Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to}$ Test Section psig.
206	2		20		0.20	0
207	4		20		0.52	0
208	6		20		0.90	0
209	8		20		1.76	1.0
210	10		20		2.84	2.0
211	12		20		3.95	3.0
212	14		20		5.42	4.5
213	20		20		12.32	9.0
214	30		20		26.00	18.5
215	2	0.0033	22	25	0.82	2.0
216	2	0.0059	22	25	1.58	2.0
217	2	0.0089	22	25	2.19	2.0
218	2	0.0120	22	25	2.79	2.0
219	2	0.0168	22	25	3.18	2.0
220	2	0.0222	22	25	3.95	2.0
221	2	0.0275	22	25	5.10	3.0
222	4	0.0036	22	25	2.19	1.5
223	4	0.0065	22	25	2.79	2.0
224	4	0.0098	23	25	3.74	2.5
225	4	0.0131	23	25	4.34	3.0
226	4	0.0184	23	25	5.90	4.0
227	4	0.0230	23	25	8.26	5.0
228	4	0.0299	23	25	11.17	9.0
229	6	0.0037	24	25	5.30	2.5
230	6	0.0066	24	25	5.90	3.0
231	6	0.0104	24	25	7.48	4.0
232	6	0.0147	24	25	9.60	5.0
233	6	0.0190	24	25	11.92	7.0
234	6	0.0249	24	25	13.47	10.0
235	6	0.0316	24	25	15.23	12.0
236	8	0.0038	25	25	6.49	3.0
237	8	0.0070	25	25	7.84	4.0
238	8	0.0113	25	25	9.40	7.0
239	8	0.0158	25	25	11.92	10.0
240	8	0.0213	25	25	14.64	12.0
241	8	0.0274	25	25	17.82	14.0
242	8	0.0347	25	25	20.20	18.0
243	10	0.0040	25	25	8.82	5.0
244	10	0.0076	25	25	10.00	8.0
245	10	0.0119	25	25	11.36	10.0

Table 3D. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Plug Disc Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to}$ Test Section psig.
246	10	0.0172	25	25	14.64	13.0
247	10	0.0232	25	25	16.43	15.0
248	10	0.0297	25	25	20.60	19.0
249	10	0.0363	25	25	23.02	23.0
250	12	0.0042	26	25	10.96	8.0
251	12	0.0079	26	25	11.92	11.0
252	12	0.0122	26	25	13.08	13.0
253	12	0.0180	26	25	17.82	16.0
254	12	0.0240	26	25	20.02	20.0
255	12	0.0306	26	25	22.42	24.0
256	12	0.0377	26	25	24.60	28.0
257	14	0.0043	26	24	12.50	10.0
258	14	0.0083	26	24	15.04	12.0
259	14	0.0133	26	24	17.22	15.0
260	14	0.0190	26	24	18.81	20.0
261	14	0.0250	26	24	21.60	23.0
262	14	0.0324	26	24	25.20	27.0
263	14	0.0393	26	24	25.60	30.0
264	20	0.0051	27	25	22.01	18.0
265	20	0.0098	27	25	24.00	22.0
266	20	0.0154	27	25	24.80	28.0
267	20	0.0223	27	25	25.80	35.0

Table 3E. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Plug Disc Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L •C	T_G •C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to}$ Test Section psig.
268	2		29		0.15	0
269	4		29		0.95	0.5
270	6		29		2.10	1.5
271	8		29		3.73	2.5
272	10		29		5.90	4.0
273	12		29		8.46	5.5
274	14		29		11.17	7.5
275	20		29		23.80	15.0
276	2	0.0032	29	25	1.80	1.0
277	2	0.0060	29	25	2.36	1.0
278	2	0.0089	29	25	2.78	1.5
279	2	0.0131	29	25	3.73	1.5
280	2	0.0170	29	25	4.12	2.0
281	2	0.0222	29	25	5.30	2.5
282	2	0.0275	29	25	7.68	5.0
283	4	0.0036	29	25	2.78	2.0
284	4	0.0065	29	25	4.71	2.0
285	4	0.0100	29	25	6.49	3.0
286	4	0.0140	29	25	7.68	3.5
287	4	0.0187	29	25	8.82	4.0
288	4	0.0240	29	25	11.52	6.0
289	4	0.0297	29	25	14.26	11.0
290	6	0.0037	29	25	7.68	4.0
291	6	0.0070	29	25	9.20	5.0
292	6	0.0107	29	25	10.79	6.0
293	6	0.0153	29	25	12.31	8.0
294	6	0.0203	29	25	15.04	10.0
295	6	0.0260	29	25	18.42	13.0
296	6	0.0341	29	25	20.80	16.0
297	8	0.0039	30	25	10.19	15.0
298	8	0.0075	30	25	11.72	8.0
299	8	0.0120	30	25	14.07	11.0
300	8	0.0163	30	25	17.03	13.0
301	8	0.0231	30	25	20.41	16.0
302	8	0.0289	30	25	20.40	20.0
303	8	0.0330	30	25	26.59	24.0
304	10	0.0043	30	25	14.06	10.0
305	10	0.0081	30	25	16.22	13.0
306	10	0.0133	30	25	19.21	16.0
307	10	0.0184	30	25	21.02	20.0

Table 3E. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Plug Disc Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
308	10	0.0251	30	25	25.60	23.0
309	10	0.0315	30	25	27.40	26.0
310	12	0.0045	30	25	17.82	12.0
311	12	0.0088	30	25	19.02	15.0
312	12	0.0138	30	25	21.61	18.0
313	12	0.0194	30	25	24.00	23.0
314	12	0.0261	30	25	27.20	28.0
315	14	0.0047	31	24	22.01	17.0
316	14	0.0091	31	24	23.20	21.0
317	14	0.0150	31	24	26.59	25.0

Table 3F. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Composition Disc Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
318	2		19		0.15	0
319	4		19		0.35	0
320	6		19		0.90	0.9
321	8		19		1.70	1.3
322	10		20		2.55	2.0
323	12		20		3.75	3.0
324	14		20		5.10	4.1
325	20		20		11.50	8.0
326	30		20		26.20	18.5
327	2	0.0031	21	27	0.80	2.0
328	2	0.0057	21	27	1.60	2.0
329	2	0.0086	21	27	2.00	3.0
330	2	0.0129	21	27	2.40	3.0
331	2	0.0165	22	27	2.80	3.0
332	2	0.0208	22	27	3.15	3.0
333	2	0.0274	22	27	4.35	3.0
334	4	0.0031	22	26	1.20	2.0
335	4	0.0061	22	26	2.80	3.0
336	4	0.0078	22	26	3.55	3.5
337	4	0.0132	22	26	4.35	4.0
338	4	0.0171	22	26	5.70	5.0
339	4	0.0232	22	26	8.00	6.0
340	4	0.0294	22	26	9.80	8.0
341	6	0.0035	23	26	4.35	4.0
342	6	0.0064	23	26	5.90	4.0
343	6	0.0101	23	26	7.30	4.0
344	6	0.0141	23	26	8.80	6.0
345	6	0.0190	23	26	11.00	8.0
346	6	0.0256	23	26	12.90	12.0
348	8	0.0037	24	26	6.30	12.0
349	8	0.0069	24	26	7.30	6.5
350	8	0.0115	24	26	9.20	8.0
351	8	0.0157	24	26	11.40	9.5
352	8	0.0215	24	26	13.65	12.0
353	8	0.0268	24	26	17.05	15.0
354	8	0.0353	24	26	19.20	17.0
355	10	0.0039	25	26	7.50	7.0
356	10	0.0075	25	26	9.00	8.0
357	10	0.0123	25	26	11.35	12.0
358	10	0.0170	25	26	13.45	14.0

Table 3F. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Composition Disc Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
359	10	0.0224	25	26	16.60	17.0
360	10	0.0296	25	26	19.65	21.0
361	10	0.0360	25	26	20.60	23.0
362	12	0.0041	26	26	10.00	7.0
363	12	0.0079	26	26	11.00	9.0
364	12	0.0121	26	26	13.10	12.0
365	12	0.0177	26	26	15.60	15.0
366	12	0.0245	26	26	19.60	22.0
367	12	0.0305	26	26	21.60	24.0
368	12	0.0384	26	26	23.60	25.0
369	14	0.0042	27	26	12.10	12.0
370	14	0.0082	27	26	14.05	14.0
371	14	0.0129	27	26	15.00	16.0
372	14	0.0179	27	26	16.80	20.0
373	14	0.0255	27	26	20.20	25.0
374	14	0.0307	27	26	22.60	28.0
375	14	0.0389	27	26	24.80	30.0
376	20	0.0051	27	26	20.60	20.0
377	20	0.0098	27	26	23.80	24.0
378	20	0.0155	27	26	24.00	28.0

Table 3G. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Composition Disc Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
379	2		20		0.15	0
380	4		20		0.30	0
381	6		20		0.95	0
382	8		20		1.80	1.4
383	10		20		2.90	2.0
384	12		20		3.90	3.0
385	14		20		5.50	4.2
386	20		20		12.70	9.0
387	2	0.0032	22	24	1.60	0.1
388	2	0.0060	22	24	2.00	1.0
389	2	0.0096	22	24	2.40	1.0
390	2	0.0128	22	24	2.80	1.0
391	2	0.0168	22	24	3.15	1.5
392	2	0.0224	22	24	4.15	3.0
393	2	0.0268	22	24	5.30	3.5
394	4	0.0031	22	24	1.80	0.5
395	4	0.0068	22	24	3.15	1.0
396	4	0.0096	22	24	3.75	2.0
397	4	0.0133	22	24	4.90	3.0
398	4	0.0173	21	24	6.50	5.0
399	4	0.0233	21	24	8.05	5.0
400	4	0.0285	21	23	10.80	7.5
401	6	0.0034	22	23	4.90	3.0
402	6	0.0064	22	23	5.30	5.0
403	6	0.0105	22	23	7.50	6.0
404	6	0.0150	22	23	9.45	8.0
405	6	0.0204	22	23	11.35	9.0
406	6	0.0254	22	23	13.65	12.0
407	6	0.0321	22	23	15.00	15.0
408	8	0.0038	22	23	7.30	5.0
409	8	0.0070	22	23	8.05	6.0
410	8	0.0111	22	23	9.60	10.0
411	8	0.0160	22	23	11.75	12.0
412	8	0.0215	22	23	13.70	13.0
413	8	0.0273	22	23	16.00	15.0
414	8	0.0350	22	23	19.80	18.0
415	10	0.0046	22	23	8.80	7.0
416	10	0.0077	22	23	9.60	8.0
417	10	0.0124	22	23	11.40	10.0

Table 3G. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Composition Disc Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to\ Test\ Section}$ psig.
418	10	0.0169	22	23	14.25	14.0
419	10	0.0225	22	23	17.60	16.0
420	10	0.0298	22	23	19.65	20.0
421	10	0.0376	22	23	22.60	25.0
422	12	0.0012	22	23	10.80	8.0
423	12	0.0081	22	23	11.70	12.0
424	12	0.0128	22	23	13.65	15.0
425	12	0.0183	22	23	16.80	18.0
426	12	0.0238	22	23	19.60	20.0
427	12	0.0316	22	23	22.80	25.0
428	12	0.0394	22	23	25.00	28.0
429	14	0.0044	22	23	13.45	10.0
430	14	0.0085	22	23	14.45	13.0
431	14	0.0134	22	23	15.60	16.0
432	14	0.0190	22	23	17.80	20.0
433	14	0.0254	22	23	20.80	25.0
434	14	0.0332	22	23	25.00	28.0
435	14	0.0413	22	23	26.40	32.0
436	20	0.0051	24	23	22.85	17.0
437	20	0.0094	24	23	25.60	23.0

Table 3H. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Bevel Seat Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
438	2		19		0.15	0
439	4		19		0.45	1.0
440	6		19		0.95	1.0
441	8		19		1.90	1.5
442	10		19		2.90	2.5
443	12		19		4.25	3.5
444	14		19		5.60	4.2
445	20		19		13.05	10.0
446	2	0.0033	20	23	1.60	0
447	2	0.0059	20	23	2.15	2.0
448	2	0.0090	20	23	2.15	2.0
449	2	0.0124	20	23	2.80	3.0
450	2	0.0168	20	23	3.40	3.0
451	2	0.0212	20	23	3.90	3.5
452	2	0.0273	20	22.5	5.10	3.5
453	4	0.0034	21	22.5	2.55	0
454	4	0.0064	21	22.5	3.40	0
455	4	0.0097	21	22.5	3.75	3.5
456	4	0.0135	21	22.5	5.10	4.0
457	4	0.0174	21	22.5	6.70	4.0
458	4	0.0229	21	22.5	8.05	6.0
459	4	0.0294	21	22.5	10.00	7.5
460	6	0.0035	22	22.5	4.90	3.5
461	6	0.0072	22	22.5	5.70	5.0
462	6	0.0103	22	22.5	7.50	6.0
463	6	0.0150	22	22.5	9.00	7.0
464	6	0.0194	22	22.5	11.35	9.0
465	6	0.0252	22	22.5	13.45	11.0
466	6	0.0317	22	22.5	15.20	13.0
467	8	0.0038	22.5	22	7.30	5.0
468	8	0.0071	22.5	22	7.85	5.0
469	8	0.0117	22.5	22	9.60	8.0
470	8	0.0160	22.5	22	11.55	10.0
471	8	0.0215	22.5	22	14.65	13.0
472	8	0.0272	22.5	22	17.40	15.0
473	8	0.0341	22.5	22	19.25	17.0
474	10	0.0040	23.5	22	8.80	6.0
475	10	0.0077	23.5	22	9.80	9.0
476	10	0.0119	23.5	22	11.80	12.0
477	10	0.0169	23.5	22	13.65	14.0
478	10	0.0225	23.5	22	17.85	16.0

Table 3H. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Bevel Seat Globe Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
479	10	0.0294	23.5	22	19.60	19.0
480	10	0.0268	23.5	22	22.45	23.0
481	12	0.0042	24	22	10.40	5.0
482	12	0.0080	24	22	11.95	8.0
483	12	0.0125	24	22	13.30	11.0
484	12	0.0180	24	22	17.00	15.0
485	12	0.0244	24	22	19.85	20.0
486	12	0.0308	24	22	21.40	25.0
487	12	0.0373	24	22	24.00	27.0
488						
489	14	0.0044	24.5	22	12.15	8.0
490	14	0.0082	24.5	22	14.25	11.0
491	14	0.0132	24.5	22	15.40	15.0
492	14	0.0185	24.5	22	17.40	19.0
493	14	0.0244	24.5	22	20.40	25.0
494	14	0.0310	24.5	22	24.00	30.0
495	14	0.0398	24.5	22	25.80	35.0

Table 31. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Bevel Seat Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
496	2		24		0.15	0
497	4		24		0.45	0
498	6		24		1.10	0.3
499	8		24		2.10	1.0
500	10		24		3.40	2.0
501	12		24		4.70	4.0
502	14		24		6.80	5.0
503	20		24		15.10	10.5
504	2	0.0033	24.5	23	2.40	1.5
505	2	0.0062	24.5	23	2.55	1.5
506	2	0.0096	24.5	23	2.80	1.5
507	2	0.0132	24.5	23	3.10	2.0
508	2	0.0170	24.5	23	3.75	3.0
509	2	0.0223	24.5	23	4.90	4.0
510	2	0.0276	24.5	23	5.70	4.0
511	4	0.0034	26	23	2.80	0
512	4	0.0065	26	23	3.35	3.0
513	4	0.0103	26	23	3.95	3.0
514	4	0.0140	26	23	5.30	4.0
515	4	0.0184	26	23	7.50	5.0
516	4	0.0231	26	23	8.30	6.0
517	4	0.0294	26	23	10.00	9.0
518	6	0.0036	27	23	5.70	3.0
519	6	0.0068	27	23	6.50	4.0
520	6	0.0109	27	23	7.70	4.0
521	6	0.0149	27	23	9.80	7.0
522	6	0.0196	27	23	11.75	8.5
523	6	0.0254	27	23	13.90	10.0
524	6	0.0319	27	23	16.65	13.0
525	8	0.0038	27	23	7.1	5.0
526	8	0.0073	27	23	8.25	6.0
527	8	0.0119	27	23	10.0	9.0
528	8	0.0163	27	23	12.5	11.0
529	8	0.0240	27	23	16.05	19.0
530	8	0.0275	27	23	18.25	16.0
531	8	0.0344	27	23	19.80	18.0
532	10	0.0042	28	23	10.55	7.0
533	10	0.0078	28	23	11.40	8.0
534	10	0.0125	28	23	12.90	11.0
535	10	0.0170	28	23	15.80	14.0

Table 31. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Bevel Seat Globe Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
536	10	0.0233	28	23	20.0	16.0
537	10	0.0300	28	23	21.6	20.0
538	10	0.0367	28	23	23.4	25.0
539	12	0.0042	28	23	11.9	9.0
540	12	0.0079	28	23	12.3	12.0
541	12	0.0127	28	23	13.9	15.0
542	12	0.0181	28	23	17.6	19.0
543	12	0.0246	28	23	21.0	23.0
544	12	0.0310	28	23	23.2	25.0
545	12	0.0378	28	23	24.8	30.0
546	14	0.0044	29	23	15.2	11.0
547	14	0.0086	29	23	17.2	14.0
548	14	0.0134	29	23	17.6	16.0
549	14	0.0187	29	23	19.6	19.0
550	14	0.0255	29	23	22.8	25.0
551	14	0.0320	29	23	25.4	30.0
552	14	0.0396	29	23	27.6	35.0

Table 3J. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Gas Line Cock Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	P_{inlet} to Test Section psig.
553	2		18		0.15	0
554	4		18		0.45	0
555	6		18		0.95	0
556	8		18		1.70	1.0
557	10		18		2.50	2.0
558	12		18		3.65	3.0
559	14		18		5.10	4.0
560	20		19		11.65	8.5
561	30		19		26.6	19.0
562	2	0.0033	19	24	1.40	1.0
563	2	0.0060	19	24	1.60	2.0
564	2	0.0091	19	24	2.00	3.0
565	2	0.0128	19	24	2.40	3.0
566	2	0.0170	19	24	3.20	3.0
567	2	0.0216	19	24	3.75	3.0
568	2	0.0275	20	24	5.30	3.5
569	4	0.0032	20	24	2.00	2.0
570	4	0.0061	20	24	3.20	3.0
571	4	0.0100	20	24	4.0	3.0
572	4	0.0137	20	24	5.3	3.5
573	4	0.0179	20	24	7.1	4.0
574	4	0.0244	20	24	8.05	5.0
575	4	0.0295	20	24	11.2	7.0
576	6	0.0036	21	24	4.5	2.0
577	6	0.0066	21	24	5.9	3.0
578	6	0.0108	21	24	6.9	4.0
579	6	0.0147	21	24	9.2	5.0
580	6	0.0199	21	24	11.7	7.0
581	6	0.0255	21	24	13.5	10.0
582	6	0.0320	21	24	16.05	13.0
583	8	0.0037	21.5	24	7.3	5.0
584	8	0.0071	21.5	24	7.9	6.0
585	8	0.0111	21.5	24	10.0	6.5
586	8	0.0161	21.5	24	11.75	9.0
587	8	0.0214	21.5	24	15.0	13.0
588	8	0.0275	21.5	24	17.8	16.0
589	8	0.0343	21.5	24	19.45	20.0
590	10	0.0039	22	24.5	8.45	7.0
591	10	0.0075	22	24.5	9.45	8.0
592	10	0.0119	22	24.5	11.9	10.0

Table 3J. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Gas Line Cock Valve, Full Open

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to}$ Test Section psig.
593	10	0.0173	22	24.5	15.0	14.0
594	10	0.0228	22	24.5	17.2	18.0
595	10	0.0297	22	24.5	20.0	22.0
596	10	0.0363	22	24.5	22.2	26.0
597	12	0.0041	23	24.5	10.6	8.0
598	12	0.0077	23	24.5	11.75	10.0
599	12	0.0125	23	24.5	13.7	14.0
600	12	0.0180	23	24.5	16.8	17.0
601	12	0.0239	23	24.5	19.8	21.0
602	12	0.0309	23	24.5	22.8	25.0
603	12	0.0376	23	24.5	25.4	28.0
604	14	0.0043	23.5	24.5	12.5	9.0
605	14	0.0081	23.5	24.5	15.2	13.5
606	14	0.0133	23.5	24.5	15.6	16.0
607	14	0.0189	23.5	24.5	19.65	20.0
608	14	0.0253	23.5	24.5	21.4	24.0
609	14	0.0322	23.5	24.5	23.2	28.0
610	14	0.0383	23.5	24.5	25.2	33.0
611	20	0.0051	24.5	24.5	23.6	18.0
612	20	0.0098	24.5	24.5	25.8	23.0

Table 3K. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Gas Line Cock Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to\ Test\ Section}$ psig.
613	2		25.5		0.15	0
614	4		25.5		0.80	0
615	6		25.5		1.70	1.0
616	8		25.5		3.40	2.0
617	10		25.5		5.30	3.5
618	12		25.5		7.3	5.0
619	14		25.5		10.1	6.5
620	20		25.5		22.2	14.0
621	2	0.0033	26	24	2.0	1.0
622	2	0.0064	26	24	2.8	2.0
623	2	0.0097	26	24	3.55	2.0
624	2	0.0131	26	24	4.1	3.0
625	2	0.0170	26	24	5.3	3.0
626	2	0.0226	26	24	6.3	3.5
627	2	0.0275	26	24	6.9	4.0
628	4	0.0034	27	24	3.1	2.0
629	4	0.0065	27	24	4.9	3.0
630	4	0.0103	27	24	5.7	3.0
631	4	0.0142	27	24	7.3	4.0
632	4	0.0184	27	24	10.0	5.0
633	4	0.0242	27	24	13.1	7.0
634	4	0.0314	27	24	15.8	10.0
635	6	0.0036	28	24.5	6.5	3.0
637	6	0.0106	28	24.5	9.8	5.0
638	6	0.0155	28	24.5	12.3	8.0
639	6	0.0203	28	24.5	15.4	11.0
640	6	0.0264	28	24.5	19.05	14.0
641	6	0.0334	28	24.5	21.0	17.0
642	8	0.0039	28	24.5	9.8	6.0
643	8	0.0074	28	24.5	11.4	9.0
644	8	0.0120	28	24.5	13.5	12.0
645	8	0.0167	28	24.5	16.9	15.0
646	8	0.0228	28	24.5	19.8	18.0
647	8	0.0289	28	24.5	23.4	21.0
648	8	0.0366	28	24.5	26.4	25.0
650	10	0.0041	29	24.5	12.7	8.0
651	10	0.0081	29	24.5	14.45	13.0
652	10	0.0128	29	24.5	17.0	15.0
653	10	0.0180	29	24.5	20.0	18.0
654	10	0.0244	29	24.5	23.8	22.0

Table 3K. Data for Co-Current Flow of Air and Water in 1 Inch Test Section 194 Inches Long--Gas Line Cock Valve, 1/2 Closed

Run No.	Q_L GPM	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in. Hg.	$P_{inlet\ to}$ Test Section psig.
655	10	0.0300	29	24.5	25.8	25.0
656	12	0.0043	29.5	24.5	16.0	12.0
657	12	0.0082	29.5	24.5	16.8	15.0
658	12	0.0131	29.5	24.5	17.8	18.0
659	12	0.0185	29.5	24.5	21.8	21.0
660	12	0.0251	29.5	24.5	24.8	25.0
661	14	0.0047	30	24.5	19.4	14.0
662	14	0.0090	30	24.5	20.8	18.0
663	14	0.0136	30	24.5	21.6	21.0
664	14	0.0194	30	24.5	23.8	25.0
665	14	0.0258	30	24.5	26.4	28.0

APPENDIX III

METHOD OF CALCULATION

The calculations were programmed and computed by the IBM 650 computer of the Rich Electronic Computer Center using the Bell General Purpose System. One basic calculation program was set up, but only parts of the whole program were used for the single-phase water runs and the straight pipe runs.

The input data consisted of suitable constants plus the following eleven variables:

Run number

Q_L	GPM
μ_L	lb. mass/ft. sec.
ρ_L	lb. mass/ft.^{3}
Q_G	standard CFM
μ_G	lb. mass/ft. sec.
T_G	°C
P_G	psia.
P_{AVG}	psia.
ΔP_{EXP}	psi.
$(L/D)_V$	dimensionless

The diameter and area of the pipe, the relative roughness of the pipe, the density of air, and conversion factors were put in the computer before each series of calculations.

Calculation of Single-Phase Runs.--Three basic types of calculations were made on the computer. These were calculation of single-phase runs, calculation of the straight pipe section, and calculation of two-phase runs with test valve. When the single-phase water runs or straight pipe runs were made, variables not entering into the calculations were set equal to zero.

The following quantities were calculated by the computer.

$$W_L = Q_L \frac{1}{7.481} \rho_L \frac{1}{60} \tag{1}$$

$$Re_L = \frac{4W_L}{\pi D \mu_L} \tag{2}$$

$$u_L = \frac{Q_L}{7.481\ A\ 60} \tag{3}$$

$$f_L^{-1/2} = -2 \log_{10} \left[\frac{\epsilon}{3.7D} + \frac{2.51}{Re_L (f_L)^{1/2}} \right] \tag{4}$$

$$\left(\frac{\Delta P}{\Delta L}\right)_L = \frac{f_L\ u^2_L\ \rho_L}{D\ 2g_c\ 144} \tag{5}$$

The output data were $\left(\frac{\Delta P}{\Delta L}\right)_L$. After multiplying by the length of the test section the calculated pressure loss could be compared with the experimental value.

Calculation of Straight Pipe Section.--The same procedure as above was used in the calculation of the pressure drop per unit length for the liquid phase, and the following additional quantitites were calculated:

$$Wg = \frac{Q_G}{60}\left[\frac{20\ P_G}{T_G}\right]^{1/2} \rho_G \tag{6}$$

$$Re_G = \frac{4W_G}{\pi D \mu_G} \tag{7}$$

$$u_G = \frac{Q_G}{60\ A}\left[\frac{T_G}{20P_G}\right]^{1/2} \frac{P_G}{P_{AVG}} \tag{8}$$

$$f_G^{-1/2} = -\ 2\ \log_{10}\left[\frac{\epsilon}{3.7D} + \frac{2.51}{Re_G\,(f_G)^{1/2}}\right] \tag{9}$$

$$\left(\frac{\Delta P}{\Delta L}\right)_G = \frac{f_G\ u_G^2\ 1.5\ P_{AVG}}{D\ 2g_c\ 144\ T_G} \tag{10}$$

$$X^2 = \left(\frac{\Delta P}{\Delta L}\right)_L \Bigg/ \left(\frac{\Delta P}{\Delta L}\right)_G \tag{11}$$

$$\phi^2_{LTT} = \frac{\Delta P_{EXP}}{16.17\left(\frac{\Delta P}{\Delta L}\right)_L} \tag{12}$$

These values were then plotted in Fig. 8 to illustrate the agreement with the curve of Lockhart and Martinelli (2).

Calculation of Two-Phase Runs with Test Valve.--In the calculations of the two-phase runs with the test valve in place the same computer program was used down to equation (12). At that point ϕ^2_{LTT} was calculated by equation (13) representing the Lockhart and Martinelli (2) correlation in the turbulent-turbulent region within ± 5 per cent.

$$\phi^2_{LTT} = 16.64(X^2)^{-0.444} \tag{13}$$

$$\left(\frac{\Delta P}{\Delta L}\right)_{TP} = \phi^2\left(\frac{\Delta P}{\Delta L}\right)_L \tag{14}$$

$$\psi = \frac{\dfrac{\Delta P_{EXP}}{\left(\frac{\Delta P}{\Delta L}\right)_{TP}} - \left(\frac{L}{D}\right)_{TS} D_{TS}}{\left(\frac{L}{D}\right)_V D_{TS}} \tag{15}$$

The output data punched by the computer for the two-phase runs with valves are shown in Table 2. The value of ψ with its corresponding value of X^2 was plotted in Fig. 13.

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